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GEOLOGY OF THE CENTRAL WISE RIVER VALLEY,
PIONEER MOUNTAINS, BEAVERHEAD COUNTY, MONTANA

by

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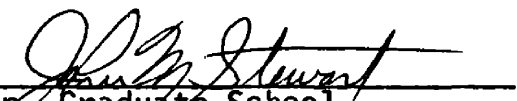
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for the degree of
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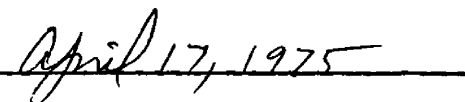
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Geology

Geology of the Central Wise River Valley, Pioneer Mountains,
Beaverhead County, Montana

Director: Donald Winston 

The central Wise River Valley is located in the north-central part of the Pioneer Mountains in southwestern Montana approximately 50 kilometers west of the Precambrian crystalline Dillon Block and 20 kilometers west of the eastern Pioneer Mountains disturbed belt.

Three Precambrian stratigraphic units are proposed: Belt 1 (oldest), Belt 2, and Belt 3 (youngest). Detrital plagioclase in the Belt 2 unit was the original criterion for mapping the Belt 1--Belt 2 contact. The Belt 3 is isolated from the two other Precambrian units by the Fourth of July fault. The Belt 1 is dominantly purple, medium to coarse grained, planar and festoon crossbedded, microcline, orthoclase, quartz meta-sandstone with lenses of matrix supported microcline, orthoclase, quartz, quartzite meta-conglomerate. The Belt 2 is typically gray to whitish gray, fine to medium grained, planar and ripple crossbedded or plane bedded, plagioclase, microcline, orthoclase, quartz meta-sandstone. White, quartz meta-sandstone and mud draped, mud-cracked and rippled meta-siltstone also occur in the Belt 2. The Belt 3 is predominantly white, gray, or reddish brown, medium to coarse grained, cross-bedded, quartz meta-sandstone interbedded with matrix supported, orthoclase, quartz, quartzite meta-conglomerate.

The Middle Cambrian Wolsey is recognized as the slightly metamorphosed shaly unit unconformably overlying Belt 3 meta-sediments and conformably underlying the Cambrian Hasmark as a gradational sequence. The laterally discontinuous nature of the Wolsey shales is probably due to terrigenous sedimentation in low areas on the Precambrian erosion surface while later carbonate deposition also occurred directly on the Precambrian knobs.

Homogeneous, tuffaceous silt, probably deposited in fluvial and lacustrine environments, form the oldest Tertiary beds. The overlying Tertiary fanglomerates formed by alluvial fan construction across the main valley.

Granitic plutons and dikes, probably related to the Philipsburg and Boulder batholiths, intruded and contact metamorphosed Precambrian and Cambrian rocks. The entire Precambrian section is regionally metamorphosed to the biotite zone, and the Cambrian rocks locally exhibit a low grade regional metamorphic fabric.

Early Laramide thrusting is represented by the Fourth of July fault which appears to be a high angle extension of the Johnson Thrust to the north. Post-Laramide faulting, including the Fourth of July fault, was of the basin and range style.

Extensive Pleistocene glaciers filled the main valleys leaving large moraines, kame terraces, and braided outwash terraces.

ACKNOWLEDGMENTS

This project was supported in part by the Society of Sigma Xi and the University of Montana Department of Geology. The outstanding cooperation of the U.S. Forest Service, Dillon office and Charles Hartgraves proves that government agencies can indeed be responsive to an individual. My thanks to E-an Zen, who pointed out two pertinent references I had overlooked and provided additional geologic information concerning the eastern Pioneer Mountains.

The comments of numerous University of Montana faculty including Robert Curry, Donald Hyndman, and James Talbot are reflected in this thesis. Gray Thompson interpreted the X-ray diffraction data.

The attention and priority given this thesis by my committee--Donald Winston, David Alt, and Colin Thorn--is greatly appreciated. I am particularly indebted to my advisor, Don Winston, whose ability and patience to teach a student how to think through a problem places him in a rare and select group of professors.

John H. Calbeck---research chemist, pilot, and Grandfather--first encouraged me to pursue a scientific education and career.

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CHAPTER I

INTRODUCTION

Geologic setting

The Pioneer Mountains are situated where the Montana Disturbed Belt raps around the northwest corner of the Dillon Block (Figure 1; Harrison and others, 1974). This massive upthrown block of pre-Belt basement gneisses and schists is bounded on the north by the Willow Creek fault, and on the west by the eastern edge of the Pioneer Mountains. The Willow Creek fault was active throughout the period of Belt deposition, shedding very coarse grained fanglomerates of the LaHood Formation on the north down-thrown side, which have been mapped as far west as the Highland Mountains near Divide, Montana (McMannis, 1963; Hawley, 1973). Neither the LaHood Formation nor the Willow Creek fault have been traced west of the Highland Mountains, although a westerly projection of the Willow Creek fault passes through the north end of the Pioneer Mountains (Figure 1). In recent years, mining geologists working near Calvert Hill (Figure 2, northwest corner of the Pioneer Mountains) have reported LaHood type rocks (C. Seel, General Electric Corp., verbal commun., 1972).

Complexly folded and faulted Mesozoic and Paleozoic strata were compressed against the west side of the Dillon Block during early Laramide time forming the eastern side of the Pioneer Mountains. Later Laramide granites intruded these Phanerozoic rocks, particularly in the western part of the eastern Pioneer disturbed belt. In contrast, the western two thirds of the Pioneer Mountains consists of broadly folded Belt

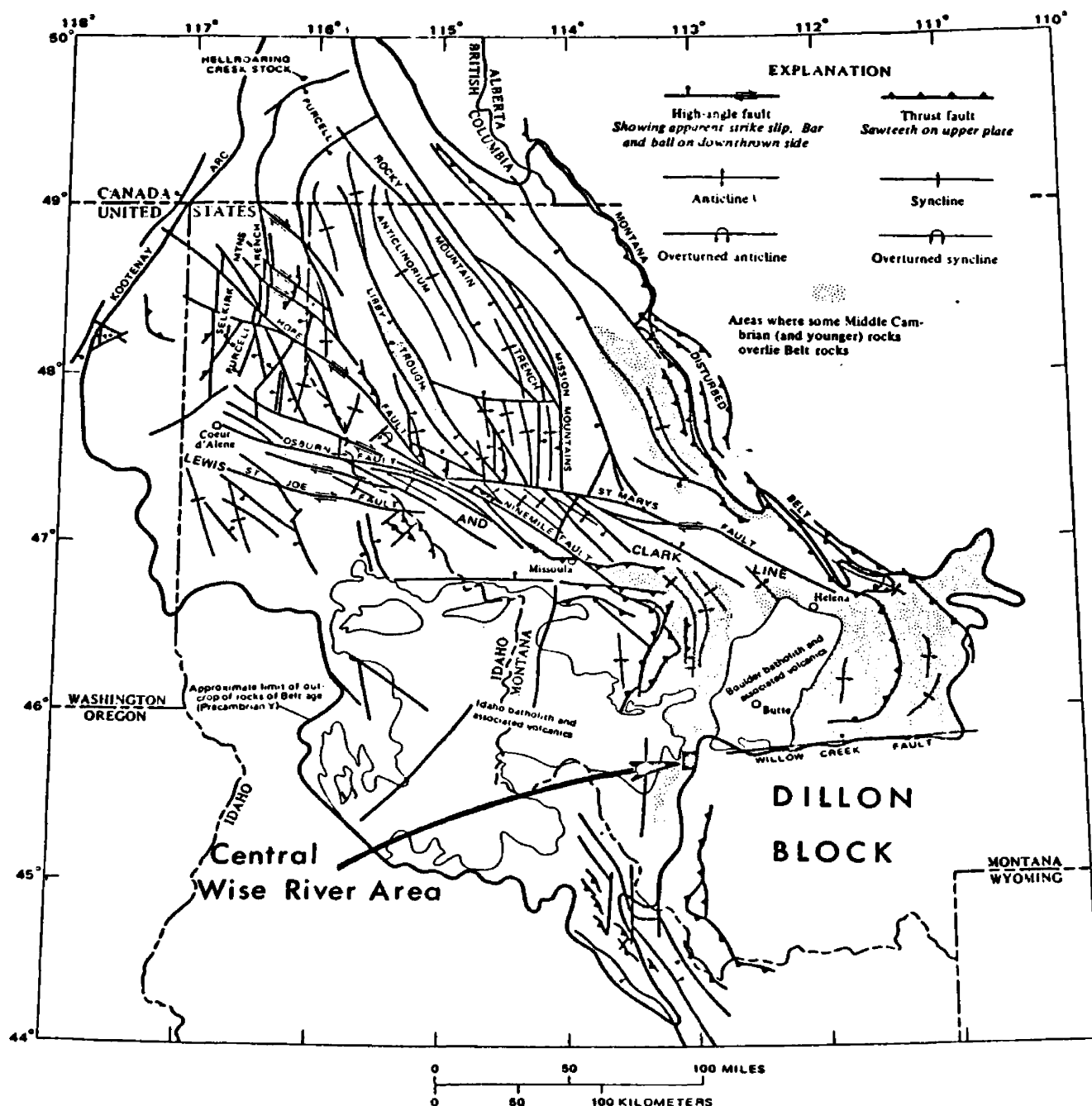


Fig. 1. Geologic index map showing the location of the central Wise River Valley area. Principal folds and faults in Belt terrane. Compilation by J. E. Harrison: revised from Bayley and Muehlberger (1968), largely through application of as-yet-unpublished 1:25,000 and 1:250,000 geologic mapping by various members of the U.S. Geological Survey, including A. B. Griggs, J. D. Wells, M. R. Mudge, R. L. Earhart, J. E. Harrison, F. K. Miller, G. D. Robinson, and E. T. Ruppel. (After Harrison and others, 1974)

meta-sediments, granitic plutons, and granitic gneisses. The Wise River Valley generally marks the boundary between these two geologically distinct terrains. Although the disturbed belt along the eastern side of the Pioneer Mountains has been examined in detail (Figure 2), little geologic information has been published concerning the western two thirds of the mountain range.

Purpose of study

This thesis hopefully initiates the research necessary to understand the regional geologic framework of the central and western Pioneer Mountains. The principal goals are as follows: (1) to map part of the large gap in the general geology of southwestern Montana, (2) to collect primary level data on the Precambrian stratigraphy, and (3) to delineate more specific research problems for future study. The third objective, which has many facets, is an important part of any aerial geologic study, and much of this paper is directed toward outlining future research problems. I have not hesitated to propose explanations to many problems, although the data may have been inconclusive. Every effort was made to present these in an honest manner, fully realizing that much work needs to be done and that reinterpretations based upon additional research are not only possible, but probable. Multiple hypotheses and their ramifications are discussed wherever they become evident.

Location and method of study

The map area (Figures 1 and 2) is approximately rectangular in shape and centers on the junction between the Wise River and Pattengail Creek, about 15 kilometers south of the town of Wise River.

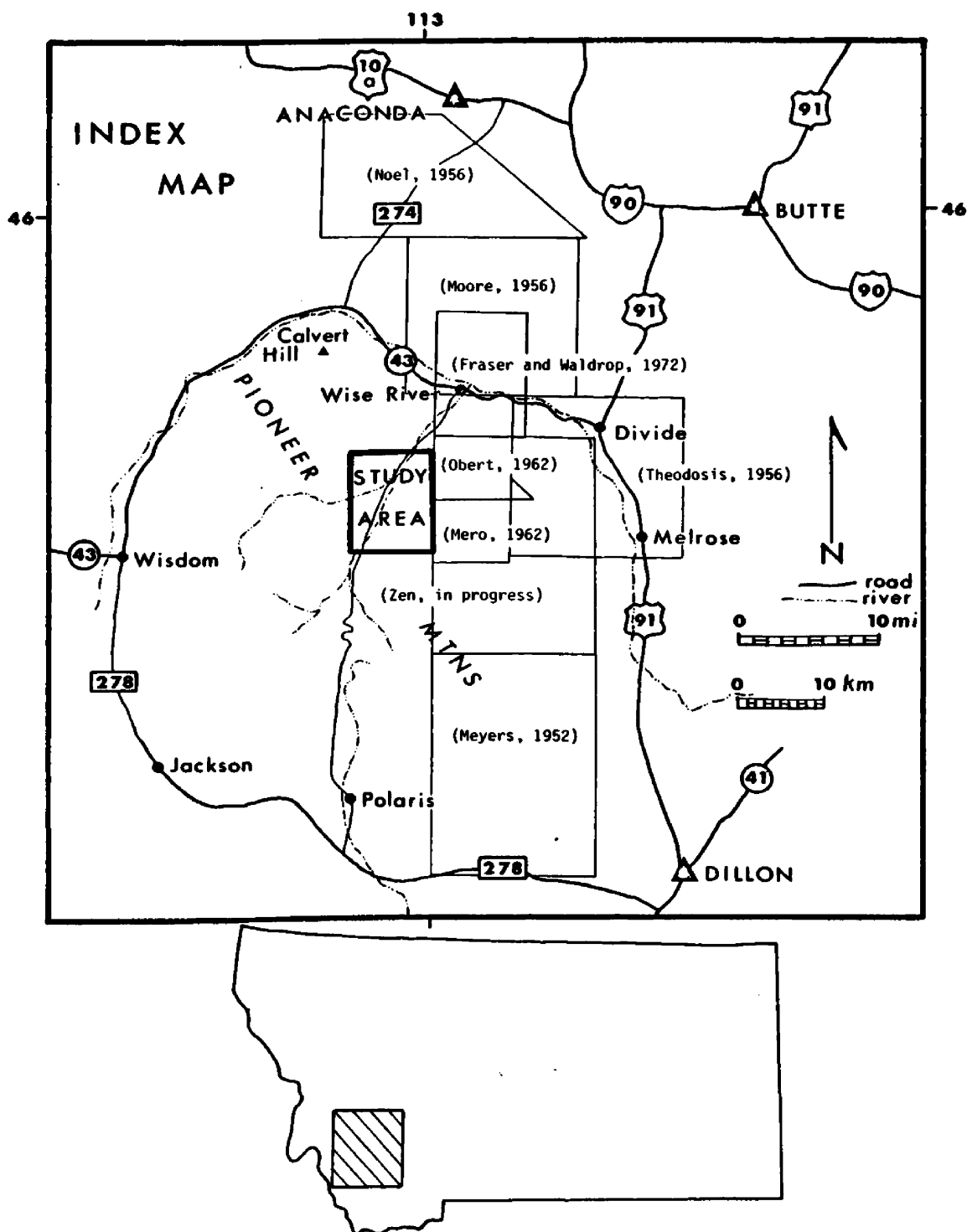


Fig. 2. Index map showing the location of the central Wise River Valley area and previous aerial geologic studies within the Pioneer Mountains.

Approximately 104 square kilometers of the central Pioneer Mountains was mapped during the summer of 1972, and critical areas were re-examined over several weekends during 1973 and 1974. Because the stratigraphic sequence was poorly known and many key areas were covered, this initial study is general in nature. Mapping was done on U.S. Forest Service resource air photographs at a 1:15,840 scale. Data was then plotted onto a USFS planimetric map (1:31,680) upon which 200 foot interval contours were later superimposed from the Dillon, Montana 1:250,000 topographic map. Regional and geomorphic features were studied through the use of USFS high altitude air photographs.

Previous work

Although the glacial deposits of the Wise River and Pattengail glaciers were briefly described by W. C. Alden (1953), the bedrock geology in the western two thirds of the Pioneer Mountains, including the thesis area, has not been studied.. Much information useful to this study has been drawn from the several university and government sponsored field projects north and east of the central Wise River area (Figure 2; Fraser and Waldrop, 1972; Mero, 1962; Meyers, 1952; Moore, 1956; Noel, 1956; Obert, 1962; Theodosius, 1956; Zen, U.S. Geological Survey, Washington, in progress).

CHAPTER II

PRECAMBRIAN SYSTEM

Introduction--The Belt problem

Precambrian Belt strata crop out over 52 square kilometers of the central Wise River area. Because scree mantles most of the Belt hill slopes, outcrops occur as scattered pinnacles and cliffs, usually within the middle third of scree covered mountainsides. Lithologies of these Precambrian sedimentary rocks grade from mudcracked meta-siltstones to coarse grained, matrix supported, meta-conglomerates. A major problem in the Belt sequence lies in delineating mappable lithologic units within a section of completely gradational rock types. Furthermore, the Belt stratigraphy of southwestern Montana is probably less well known and described than anywhere else in the Northwest.

It should be noted that the entire section has been metamorphosed to the biotite zone of the greenschist facies. Because this is a minor mineralogical characteristic which has not severely disrupted the sedimentary fabric, the lithologies discussed here will reflect the original sedimentary nature of the rocks, ignoring for the time being the relatively minor and mostly microscopic effects of regional metamorphism.

Delineating mappable units

Three separate units are proposed and outlined on the geologic map (Plate 1). During the summer of 1972, when the bulk of the field work was completed, the Precambrian was mapped "undifferentiated". Not until

thin sections were compared with hand specimens and field descriptions did the possibility of differentiating stratigraphic units come into focus.

The map units, Belt 1 and 2 are respectively based upon the absence or presence of detrital plagioclase in thin section. This is obviously not the kind of criterion which can be used directly in field mapping, but combined with general rock descriptions it provides a workable stratigraphic indicator which cuts across the confusion of gradational lithology. The Belt 3 is isolated from the rest of the Belt section by the Fourth of July fault.

Belt 1

The Belt 1 is the oldest Belt unit in the central Wise River area and appears to comprise about 360-610 meters of coarse to fine grained sandstone and conglomerate. It is conformably overlain by the Belt 2 unit, but the bottom of the Belt 1 is not exposed within the map area.

Color. Rock color, an important characteristic, is generally dark purple to purplish gray. White, whitish gray, and gray, in decreasing order of abundance occur less commonly.

Lithology of sandstone beds. Coarse and medium grained, moderately to well sorted sandstone beds dominate the Belt 1 unit. Only rare beds, reaching 10-20 centimeters in thickness, have a clay content greater than one percent. The mineralogy of the sandstone beds and the sand matrix of conglomeratic zones is quite consistent. Quartz grains always comprise 80-90% of the grains while microcline and orthoclase account for most of the remaining 5-20%. Detrital muscovite, usually bent around

the sand grains, is also common (trace-3%). Heavy minerals such as magnetite, ilmenite, zircon, sphene, and tourmaline typically form placers along crossbeds and bedding planes. The coarse to medium grained sandstones are thickly bedded with local thinly bedded, gray colored, fine grained sandstones which weather to "shaly" appearing outcrops. Average grain size is about 0.5 millimeters, the boundary between medium and coarse sand. Very high and extremely poor levels of sorting are equally rare. Quartz grains are generally larger and more angular than feldspar grains. Locally, angular feldspar grains are nearly euhedral whereas the quartz is well rounded, suggesting multiple sources.

Sedimentary structures. Planar or tabular, festoon, and ripple crossbeds are the most abundant sedimentary structures. Where medium and coarse grained sandstones are interbedded with thin, fine grained sand layers, loading and scour features are common. Mudclasts are locally prominent in medium grained sandstones which sharply overlie very fine grained sandstones, but no clay layers were ever observed. Some fine grained beds are crudely graded. Cyclic upward fining sequences with progressively smaller bed features are characteristic of the Belt 1 unit (for example the 75-150 foot interval of the partial Belt 1 section, Figure 5).

Conglomerates. Probably the most distinctive feature of this unit is the 15 to 30 meter thick, matrix supported conglomerate lenses which occur within the middle to lower 120-240 meters (Figures 3 and 4). The maximum cobble size is 100 millimeters with 50-60 millimeter pebbles very common and 15-25 millimeter pebbles most abundant. Virtually all large pebbles and cobbles are quartz or quartzite. Generally the quartzite

pebbles are composed of stretched composite quartz grains with strong undulose extinction. Other varieties include composite quartz with straight to slightly undulose extinction, common quartz, and chert. The quartz and quartzite pebbles are white for the most part, but hematite fracture filling imparts various shades of red to some pebbles. Chert pebbles are typically white or whitish gray. Smaller pebbles include the above plus orthoclase, microcline, red jasper, and hematitic mud chips. The cobbles and large pebbles of all quartz types, chert, and red jasper are well rounded whereas the mud chips, orthoclase, and microcline are angular or euhedral. The pebble supporting matrix of the conglomerate is purple to purplish gray, coarse grained, poorly sorted, feldspathic, quartz sand. Together the pebbles and matrix form homogeneous beds, generally without any regular internal structures. The conglomeratic horizons are locally interrupted by small lenses of coarse grained sandstone, typically crossbedded at a low angle.

The bottom contact of the conglomeratic zones is relatively sharp, commonly underlain by festooned or planar crossbedded, coarse grained, moderately well sorted sandstone. The upper contact is gradational, marked by a decrease in pebble size and abundance. For a stratigraphic distance of about 15 meters, medium to coarse grained sandstone is interbedded with small pebbly horizons parallel to low angle crossbeds. Figure 5 is a partial section of the Belt 1 unit measured through one of the lower conglomeratic horizons.

Belt 2

The Belt 2 unit, generally composed of medium to fine grained sandstones and siltstones, conformably overlies the Belt 1. The top of the

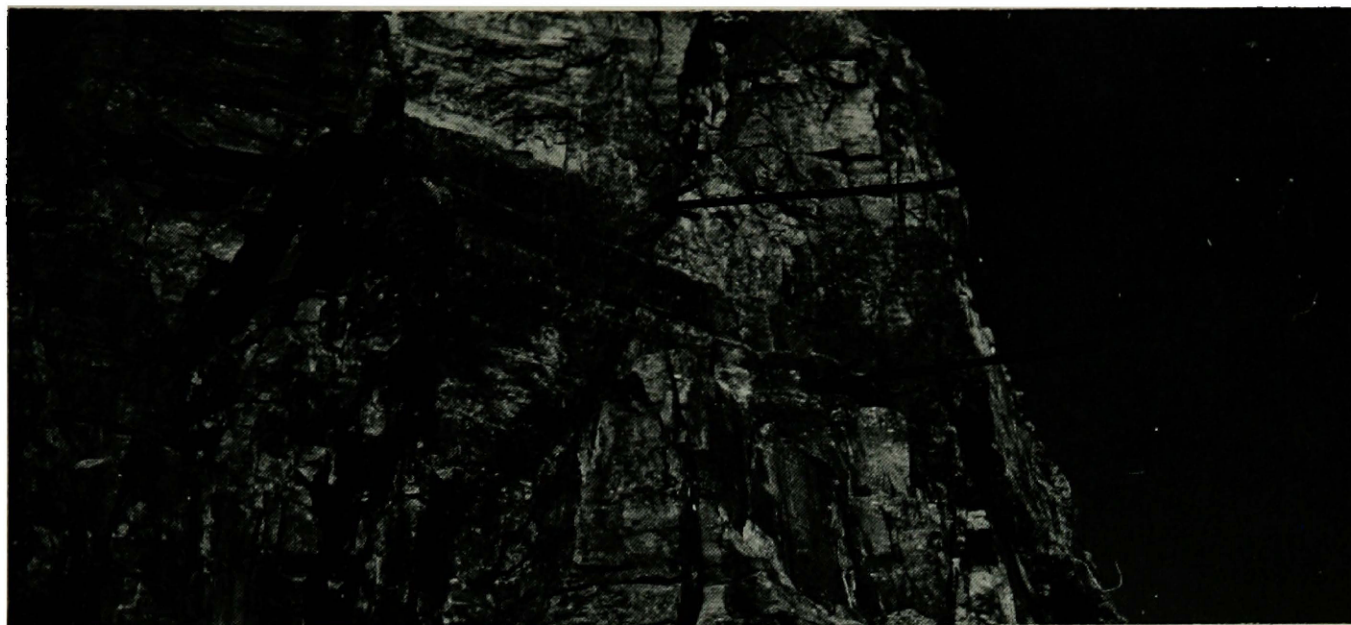


Fig. 3. Matrix supported conglomerate lenses in Belt 1 measured section (Fig. 5). Arrows indicate the location of the lenses which are about 10 meters thick at this locality.



Fig. 4. Close up of matrix supported conglomerate. Same outcrop as Figure 3.

feet (meters)

480

(140)

440

400

(120)

360

320 (100)

280

(80)

240

200

(60)

160

120

(40)

80

(20)

40

0

Planar and festoon crossbeds in purple colored, medium grained, feldspathic, quartz sandstone grading upward into ripple crossbedded, fine to medium grained sandstone.

Gray colored, plane bedded, fine sandstone; interbedded with purple to purplish gray, fine-medium grained, plane bedded and ripple crossbedded, feldspathic, quartz sandstone.

Mud chips in medium grained, purple colored, feldspathic, quartz sandstone.

Low angle crossbeds overlying festoons in medium to coarse grained, purple colored, feldspathic, quartz sandstone.

Small pebbles along low angle crossbeds.

Ripple crossbeds and plane beds in very fine grained, gray colored, sandstone. Crude graded bedding.

Small pebbles parallel to low angle crossbeds in coarse grained, purple colored, feldspathic, quartz sandstone.

Coarse grained, matrix supported conglomerate with purple colored, coarse grained, feldspathic, quartz sand lenses and matrix.
Pebbles -- 100mm-maximum
-- 20-50mm-most commonly

Low angle crossbeds overlying planar and festoon crossbeds in medium to coarse grained, feldspathic, quartz sandstone.

Festoon and planar crossbeds in white, medium grained, feldspathic, quartz sandstone.

Fig. 5. Measured section of the lower middle part of the Belt 1 unit. Location -- center section 36 T1S R12W.

Belt 2 is not exposed within the area, but may possibly crop out to the south. Approximately 1000 meters of section are exposed along the Wise River (Plate 1), but until the detailed structure can be determined, this thickness must be considered very approximate.

Color. Color is again an important lithologic characteristic. By far the most abundantly occurring color is gray to whitish gray. White is probably a distant second and is generally associated with the near pure, medium grained, quartz sandstones. Light pinkish tints are commonly added to the white colored beds. Mint green and purple tend to be most common in the mud draped siltstones. Purple colored sandstones similar to those of the Belt 1 unit are rare, but do occur.

Lithology. The lower part of the Belt 2 unit is coarse to medium grained, feldspathic, quartz sandstone containing planar, festoon, and ripple crossbeds which are very similar to the Belt 1 unit. However, these sandstones, by contrast, contain detrital plagioclase. The plagioclase typically comprises only 2-5% of the rock, but in rare cases may reach 10%. Orthoclase and microcline are still common, but where only one feldspar is present, it appears to always be plagioclase. Quartz remains the dominant mineral, accounting for 60-90% of the sand grains. In general, the rocks of this unit are considerably more argillaceous than those of the Belt 1 unit. The clay matrix is commonly 10% and in many cases reaches 50%. The average grain size of the sand fraction is also smaller, generally falling into the medium to fine grained class. Coarse silty mudstone is also common, especially high in the section. Although sorting in the coarse fraction is typically moderate, poor to very poor sorting is not rare. Quartz grains are significantly larger

than both the plagioclase and potassium feldspar grains. The feldspar grains, however, are characteristically better rounded. Muscovite, chert, magnetite, ilmenite, zircon, sphene, and tourmaline are present as part of the sand and silt fractions, but in small quantities. Magnetite-hematite rich mud clasts occur more commonly than in the Belt 1 unit. Thickly bedded, massive, nearly pure, quartz sandstones also occur scattered through the Belt 2 section, again in contrast with the unit 1 rocks.

Sedimentary structures. Internal sedimentary structures are generally on a smaller scale than those in the lower conglomeratic unit. Low angle and planar crossbeds are quite common, but large festoons appear to be less abundant. Thick, plane bedded, fine grained sandstones are interbedded with medium grained, crossbedded sandstones. Ripple crossbeds and ripple marked bedding surfaces are typically associated with very fine grained sandstone and coarse grained siltstone. The rippled bedding planes include both sinuous current and straight wave ripples. In other cases where mud is draped over the silt, bedding surfaces are mudcracked.

Tentative correlations. The main body of Belt 1 and 2 rocks crops out along both sides of the Wise River and for at least 3-5 kilometers west of the main valley. Tertiary normal faulting north of Sheep Creek dropped a block of Belt sandstone, tentatively mapped as Belt 2, down against conglomerates and sandstones of the Belt 1. The correlation with the Belt 2 is made on the basis of thick bedding, white to pinkish white color, and near pure quartz mineralogy. However, no plagioclase was noted in the two thin sections available for study.

Differentiating between Belt 1 and Belt 2 -- A summary

The two proposed Precambrian units which have now been generally described may constitute one of the more important interpretations presented in this thesis. In order to emphasize and clarify the lithologic variation, the diagnostic characteristics are summarized in Figure 6. The differing megascopic characteristics became evident only after drawing a contact, based upon the occurrence of detrital plagioclase. Because the lithologies are gradational, a precise contact may be difficult to map using only the outcrop features. The relative abundances indicated in Figure 6 are based upon field notes, thin sections, hand samples, and memory. It is not a statistical study, and by no means should it be interpreted as such.

Belt 3

A third Belt unit crops out between Sheep Mountain and the Fourth of July fault. It nonconformably overlies or is cut by quartz diorite gneisses of unknown age and origin, and unconformably underlies slaty rocks of the Cambrian Wolsey Formation. Thickness at this locality is about 45 meters. The Belt rocks east of the Fourth of July fault near Moose Creek are tentatively correlated with the Sheep Mountain Belt 3 rocks, and are discussed separately.

Lithology near Sheep Mountain. The section is predominantly conglomeratic with subround to round quartz and quartzite pebbles up to 25-30 millimeters in diameter. Minor quantities of chalky feldspar also occur as small pebbles. The pebbles are matrix supported in coarse grained, quartz sand. The poorly sorted, medium to very coarse grained

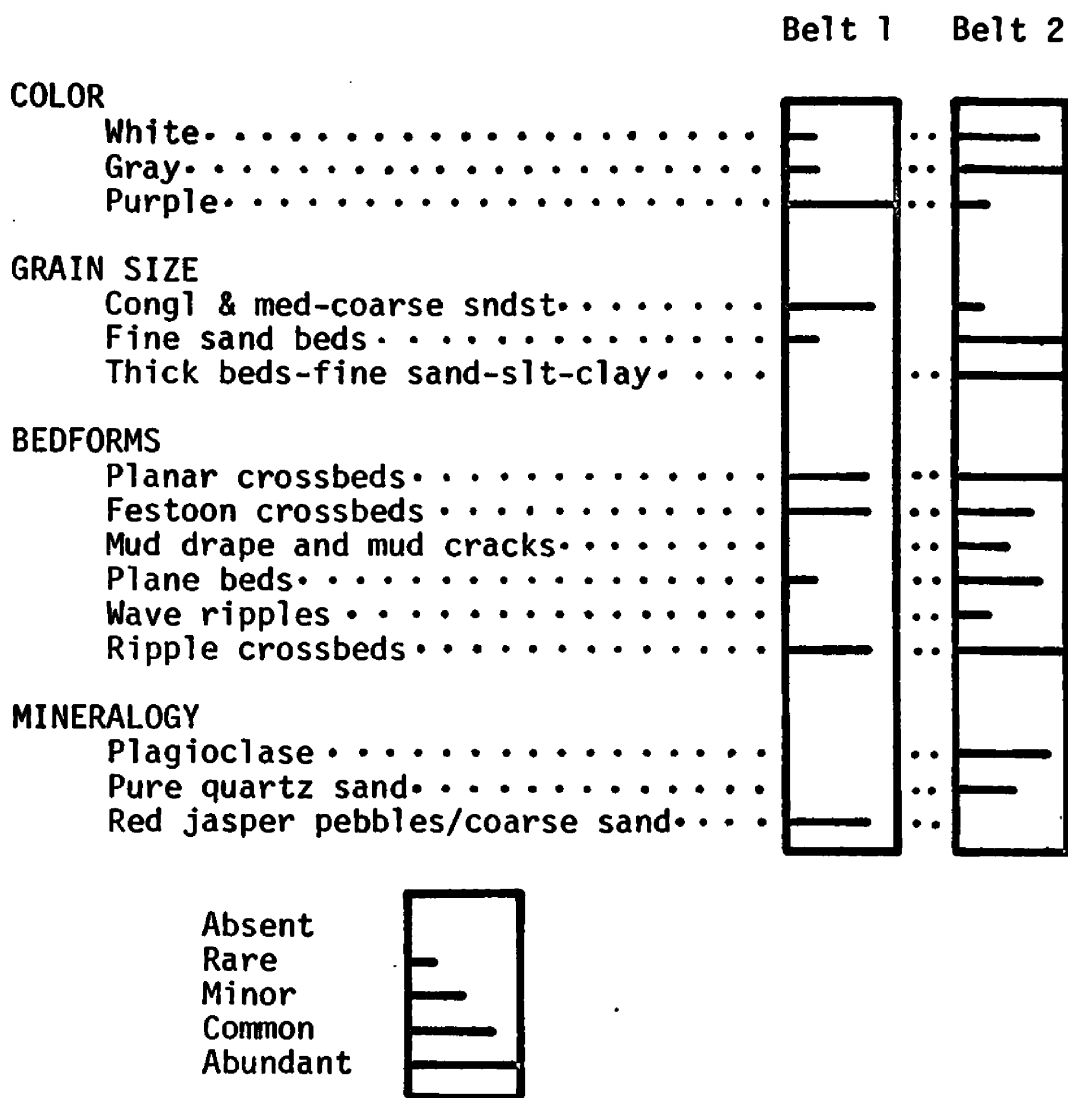


Fig. 6. The relative abundance of critical Belt 1 and Belt 2 petrographic parameters.

matrix sand is typically gray to reddish brown in color due to the oxidation of magnetite and pyrite. A single thin section of the matrix contained: 95% quartz; 2% magnetite, ilmenite, and pyrite; and trace amounts of chert, sphene, tourmaline, and zircon. Plagioclase is notably absent.

This thin conglomeratic unit is tentatively assigned to the Precambrian because of its angular discordance with the overlying Cambrian Wolsey. These Belt 3 rocks probably belong to a formation that Zen will name from exposures in the cirque wall of Black Lion Mountain (E-an Zen, verbal commun., 1973). The Belt 3 may represent the southward extension of the Precambrian Pilcher Formation at the top of the Missoula Group. On the other hand, it probably is the unit mapped as Cambrian Flathead in the local region where mappers have not distinguished the Precambrian continental deposits from the overlying Middle Cambrian marine sandstone.

Tentative Moose Creek correlation. The Belt rocks of the upper Moose Creek area, bounded on the west by the Fourth of July fault and on the north by the Moose Creek fault, are tentatively correlated with the Belt 3 found near Sheep Mountain. The Moose Creek section is about 300 meters thick compared to about 50 meters of Belt 3 west of Sheep Mountain. This is probably due to pre-Middle Cambrian erosion of a faulted Precambrian terrain. A small fault block immediately east of the Fourth of July fault apparently exhibits an unconformable Belt--Cambrian Hasmark sequence (Plate 2d).

At the Moose Creek locality, the Belt 3(?) consists of at least two thick sequences of upward fining beds. The beds are typically cement gray in color with some thick bedded, massive, white quartz sandstones. Conglomeratic layers with white and gray quartz, quartzite, and rare altered orthoclase pebbles grade upward into medium grained, crossbedded, feldspathic quartz sandstone; followed by ripple crossbedded sandstone and plane bedded, micaceous, fine grained sandstone. These plane bedded

sandstones form units up to 60 meters thick. Most of the section is micaceous including the conglomerate matrix which locally contains as much as 10% muscovite. Metamorphic biotite contributes further to the micaceous character. Quartz is the dominant mineral, comprising from 80-98% of the sand grains. Orthoclase occurs sparingly as highly altered sand grains and small pebbles. Recrystallization is locally very intense, destroying much of the original sedimentary structures. Aggregates of fine grained quartz and minor plagioclase occur in parts of these highly recrystallized zones. The plagioclase may be metamorphic albite. Alternatively, these fine grained aggregates, containing plagioclase, may be pebbles of feldspathic sand redeposited from the Belt 2 unit or other older plagioclase bearing sandstones.

In summary, the Moose Creek Belt rocks are correlated with the Belt 3 on the basis of (1) the stratigraphic relationship to the Hasmark, (2) the structural position east of the Fourth of July fault, (3) the absence of hematitic quartz pebbles, red jasper, and microcline characteristic of the Belt 1, and (4) the absence of first generation detrital plagioclase characteristic of the Belt 2. Continued mapping of these Belt rocks eastward toward Black Lion Mountain should indicate whether or not the Belt 3 correlation is valid.

Depositional environment of Belt 1, 2, and 3 units

An analysis of the chief environmental indicators--sedimentary structures and grain sizes--should begin within a lateral and vertical stratigraphic framework. All lithologic facies in the Wise River Precambrian seem to be laterally discontinuous over short distances and vertically repetitive. That is, in a three dimensional system, each

lithology would appear as a lens shaped body. Such a situation requires an environment in which the physical conditions vary radically, both across the depositional surface and vertically through time.

Figure 7 shows a typical, although idealized, association of sedimentary structures, grain sizes, and degrees of sorting in vertical section. Any particular lithology shown in Figure 7 may of course vary in thickness depending upon how long a given set of depositional conditions are maintained. By the same reasoning, the depicted sequence may be stopped or repeated from any point in the column.

Idealized interpretation. The sedimentary structures of these Precambrian sediments most closely correspond to those of alluviating river systems. The lateral lithologic changes over short distances suggests shifting channel patterns, possibly braided. Winston (1973a, 1973b, 1973c) compared the regional facies changes within the Missoula Group, particularly in the Bonner Formation, and described the group as an inter-tonguing braided stream and sea margin deltaic sequence. Boyce (1973) interpreted the Lower Belt formations, also in terms of alluvial fans, braided streams, and broad mud flats. In the following paragraphs, the lithologies and sedimentary structures typical of the Wise River Precambrian section are described on the basis of their probable analogues in modern braided rivers. The discussion systematically follows Figure 7 from bottom to top.

The coarse conglomeratic debris, transported in the upper flow regime during periods of peak discharge, would be rapidly deposited with any decrease in flow volume. The conglomerates probably represent longitudinal bars which are stable except during peak floods (Rust, 1972).

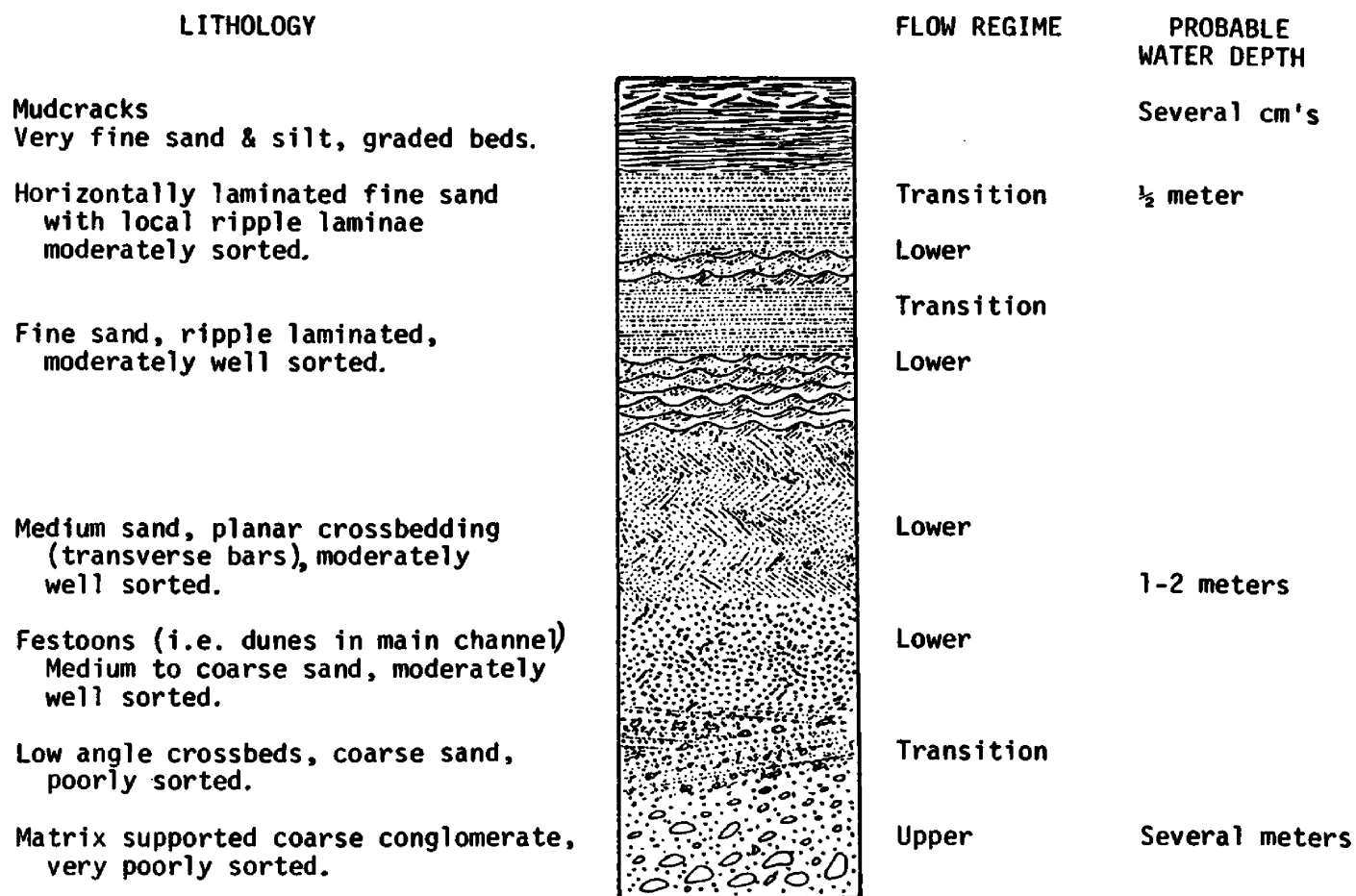


Fig. 7. An idealized vertical association of sedimentary structures, grain sizes, and degrees of sorting as related to the inferred flow regime and water depth at the time of deposition. No vertical scale to be inferred.

The Belt 1 matrix supported conglomerates generally lack distinct bedding, a characteristic related to the high sand to pebble ratio. Where stratification could be determined, the beds were nearly horizontal, suggesting that the gravel was deposited in planar sheets, probably on the flat tops of bars (Rust, 1972; Eynon and Walker, 1974). The low angle crossbedded, pebbly, poorly sorted, coarse grained sandstone which commonly overlies the conglomerate beds may represent washed out dunes characteristic of transition flow (Simons and others, 1965; Harms and Fahnstock, 1965). The crossbedded, coarse grained sand lenses within the Belt 1 conglomerate appear to be quite similar to the sand wedges described by Rust (1972) which form along the sides of gravel bars and are later dissected by channelized flow off the sides of the bars.

The festooned sand layers are typical of deposition in the main stream channels during lower discharge periods when sediment is transported in the lower flow regime (Smith, 1970; Simons and others, 1965; Harms and Fahnstock, 1965). Planar cross-stratified sand represents downstream migration of transverse bars which are most typical of the distal braided stream facies (Smith, 1970; Rust, 1972). As the flow volume diminishes, large and small scale ripples, depending upon the sediment size, form over the sand wedges and bars (Rust, 1972).

Horizontally laminated (or plane bedded) fine grained deposits are related to the grain size, flow velocity, and water depth (Matthews, 1974). The typically fine grained, plane bedded sandstones in the Wise River Precambrian strata are probably formed by thin sheets of sediment laden water streaming across the bar tops and near channel flood plains

(Harms and Fahnstock, 1965). Thin mud and silt layers, normally deposited during receding flood stages, are found on bar tops, in channels, and on the flood plain. Preservation of these muds is rare because they are easily eroded during subsequent flooding (Smith, 1970; Williams and Rust, 1969). The scarcity of muddy deposits may be used as supporting evidence for a braided stream environment (Smith, 1970). Although mud chip conglomerates are locally quite common in both the Belt 1 and Belt 2 rocks, mud layers are present only as a small part of the upper Belt 2 unit.

Proximal and distal facies. Smith (1970) originally developed a set of criteria, which was expanded by Rust (1972), for distinguishing proximal and distal braided stream facies. Using the grain size, sorting, and bedform characteristics; the Wise River Precambrian sediments can be divided into a proximal facies (Belt 1) and a distal facies (Belt 2). Figure 8 shows the distinguishing characteristics of the proximal and distal braided stream facies. The data presented here is basically the same as that of Figure 6, which compared Belt 1 and Belt 2 lithologies. The proximal-distal trend is not necessarily equivalent to a near source-distant source relationship. In addition to a greater absolute distance from the source, the distal facies may be due to: (1) finer grained source material, (2) lower elevation of the source, (3) lower overall slopes, or (4) some combination of these factors (Rust, 1972).

Braided versus meandering rivers. Although the Wise River Precambrian sequence fits into the braided stream model more easily than the meandering river model, the match is not perfect (Table 1). Of particular concern are

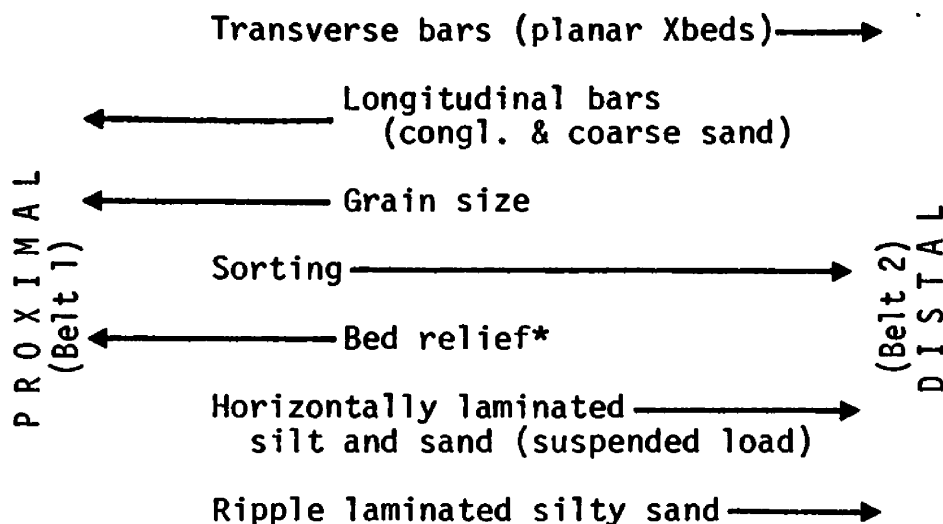


Fig. 8. Comparison of the proximal and distal braided stream facies as related to the Belt 1 and 2 units. Arrows point in the direction of increase.

*Bed relief is measured directly in modern streams, but in ancient sediments it must be estimated from the crossbed size.

Adapted from Smith (1970) and Rust (1972)

the thick beds of horizontally laminated medium to fine grained sand which are found in the Wise River Belt 2 unit. Horizontally laminated sands commonly occur as relatively thick beds situated between the festoon and ripple zones of classic point bar sequences as in the Brazos River (Bernard and others, 1970). Horizontally bedded sands deposited from transition to upper regime flow in modern braided streams are typically found as thin beds overlying planar cross-stratified beds (transverse bars) (Smith, 1970; Harms and Fahnestock, 1965). Smith (1970) also found that tops of bars in the distal braided stream facies were generally marked by ripples. This suggests that in modern braided rivers, the

upper flow regime is commonly restricted to the proximal facies where transportation and deposition typically occur during periods of high discharge. However, fluvial morphology may have been different during the unvegetated Precambrian when arid appearing landscapes were ubiquitous (Schumm, 1968). In humid regions, Precambrian braided rivers may have been at near bankfull stage most of the time because of the steady rainfall and surface runoff. Transition and upper flow regime bedforms (i.e. plane beds), which appear to be restricted to spasmodic flood episodes in modern braided streams, could have been much more common during the Precambrian.

Table 1. A comparison of meandering and braided river characteristics. Data from Smith (1970) and Matthews (1974).

<u>MEANDERING</u>	<u>BRAIDED</u>
Point bars with dunes, plane beds, and ripples	Transverse bars with planar Xbeds
Thick upward fining cycles	Thinner beds. Irregular vertical transition to finer grained deposits
Accretion by systematic lateral bar migration	Rapid vertical aggradation with rapid unpredictable lateral facies change (lenses)
Gravels as channel lag deposits	Gravels in longitudinal bars
Plane bedded sand as relatively thick part of point bar	Plane bedded sand as thin beds on tops of bars
Abundant overbank deposits	Overbank muds rarely preserved. Abundant mud chip conglomerate
Stable banks	Easily eroded banks

The "Plagioclase" line

The boundary between the Belt 1 and Belt 2 units may represent a particular event in time because the influx of detrital plagioclase was probably geologically synchronous across the depositional surface. Whether or not it was a regional or local event, or if it occurred more than once during the depositional period is not known. Until its character is more fully understood, it would be risky to use the locally established "plagioclase" line as a time or stratigraphic marker in regional correlations.

Correlation

Based upon stratigraphic position and other geologic studies in nearby areas, the Belt 1, 2, and 3 units are correlated with the Upper Precambrian Missoula Group (Moore, 1956, Fraser and Waldrop, 1972); Noel, 1956; Theodosius, 1956). Near the town of Wise River, Moore (1956) mapped similar rocks as Hellgate Quartzite (Bonner Formation--present terminology) and McNamara Formation. Obert (1962) and Mero (1962) mapped these rocks together with what is identified as Cambrian Wolsey in this paper, and assigned the whole package to the North Boulder Group, originally named by Ross (1949). The North Boulder Group was never formally described and should be abandoned in favor of the LaHood Formation (McMannis, 1963). The Belt rocks within the central Wise River Valley bear no resemblance to the extremely coarse fanglomerates of the type LaHood. Winston (1973a, b, c) has correlated the conglomerate of the Belt 1 unit as the coarse facies of the Bonner Formation. The color, mineralogy, grain size, and sedimentary structures of the Belt 1 unit are very similar

to the Bonner exposed in Flint Creek Canyon north of Georgetown Lake. The Belt 2 unit may correlate with the McNamara, if the Belt 1--Bonner Formation correlation stands up under further testing.

Because the Belt 3 unit was found only in fault contact with the Belt 2 rocks, its exact stratigraphic relationship to the rest of the Wise River Precambrian section is unknown. Although the Belt 3 underlies the Cambrian Wolsey, even its Precambrian age may be questioned. The fact that Belt 3 rocks also overlies possible Precambrian basement means that there may be an unconformity between the Belt 3 rocks and the Lower Missoula Group.

CHAPTER III

CAMBRIAN SYSTEM

Introduction

Immediately west of Sheep Mountain, Precambrian Belt strata are unconformably overlain by the Middle Cambrian Wolsey shale, which grades conformably into the Hasmark dolomite. Near Moose Creek the Wolsey is absent, the Middle to Upper Cambrian Hasmark appearing to rest unconformably on Precambrian Belt 3(?) meta-sediments. A similar case of Hasmark lying on Precambrian Belt strata has been reported near Quartz Hill, about 16 kilometers northeast of the central Wise River area (Hansen, 1952). The basal Cambrian Flathead sandstone is absent in this part of the Pioneer Mountains (Obert, 1962; Mero, 1962). Because most of the Cambrian section is covered, mapping and stratigraphic descriptions are based upon float.

Three rock units are described: (1) meta-shales and meta-siltstones (Wolsey), (2) shaly dolomite (Wolsey-Hasmark transition zone, mapped as Hasmark), and (3) relatively pure crystalline dolomitic marble (Hasmark). Because the reddish iron-stained shaly dolomite of the transition zone was easily differentiated from the Wolsey meta-shales in the float, the upper contact of the Wolsey and the lower contact of the Hasmark was mapped at that point. A discussion of the interpretative disagreement over the Precambrian-Wolsey and Wolsey-Hasmark contacts is presented at the end of this chapter.

Wolsey Formation

Lithology. The Wolsey Formation, a sequence of meta-shales and meta-siltstones, is estimated to be about 75 meters thick. The color varies from light greenish gray to dark gray with locally rusty brown colors, and depending upon the grain size (clay to very fine sand), the rock are either slaty or phyllitic due to a crude foliation. No carbonate was observed in these clastic rocks. However, Obert (1962) measured a section of Wolsey in the cirque wall on the north side of Sheep Mountain which contains a substantial quantity of dolomite and dolomitic shale not recognized on the west side of the mountain. It seems likely that Obert (1962) and Mero (1962) mapped the meta-shale unit underlying the Hasmark as a Precambrian argillite. The rocks that they mapped as Wolsey are classified in this report as the Wolsey-Hasmark transition zone and are included in the Hasmark. Table 2 summarizes the Wolsey lithology from descriptions of the float west of Sheep Mountain.

Correlation and age. The Wolsey Formation, originally described by Weed (1899), was studied throughout southwestern Montana by Hansen (1952) who found the thickness to vary from about 22 to 122 meters. In central and southwestern Montana the Wolsey is commonly a greenish gray, brownish gray, or purplish gray micaceous shale. The shaly layers are typically fissile with interlaminated thinly bedded, brownish gray, sandstone and brownish gray limestone. Locally it is sandy enough to be called an argillaceous sandstone. In other areas there is a middle limestone member with argillaceous limestone and intraformational limestone conglomerate (Hansen, 1952). In extreme southwestern Montana, the Wolsey is locally

Table 2. The Wolsey Formation west of Sheep Mountain
Generalized lithology from float. No
relative thicknesses to be inferred. Total
thickness is about 75 meters.

	Wolsey-Hasmark transition zone
Upper	Light greenish gray meta-siltstone with fracture cleavage not parallel to bedding. Subparallelism of platy minerals gives rock a phyllitic sheen.
	Meta-siltstone with crude slaty cleavage; very dark gray to slightly rusty on weathered surface, dark bluish gray on fresh surface.
Lower	Meta-siltstone with moderately developed slaty cleavage. Where coarser grained it is slightly phyllitic. Dark gray to dark grayish brown on weathered surface, dark gray with iron stained bands on fresh surface.
	Angular unconformity Precambrian Belt 3 unit

absent, which Hansen (1952) suggests may be due to post-Wolsey -- pre-Hasmark erosion. Carbonate deposition occurring locally on Precambrian topographic highs with terrigenous sediments of the Wolsey collecting only in the deeper basins is a more likely explanation.

In the Philipsburg region, Emmons and Calkins (1913) defined the Silver Hill Formation which correlates with the Wolsey. The Silver Hill contains three members: a lower shale member, a middle limestone member, and an upper shale member. The lower shale member is identical to the typical Wolsey, and the upper shale is similar but contains a greater percentage of inter-laminated limestone than does the Wolsey (Hansen, 1952).

The Middle Cambrian age is based upon the trilobite genus Kootenia (Lochman, 1949). No fossils were found west of Sheep Mountain, but Zen reports trilobite fossil fragments from areas on the northeast side of Sheep Mountain (Zen, verbal commun., 1974).

Hasmark Formation

Transition zone lithology. Because the heavily iron stained dolomitic rocks of the transition zone were easily recognized in the float, their appearance and the disappearance of the grayish meta-shales and meta-siltstones was used in the field to map the Wolsey-Hasmark contact. These rocks were therefore included in the Hasmark map unit, and are discussed in this section. Table 3 describes the general sequence of lithologies observed in the float through the transition zone.

Hasmark dolomite lithology. The Hasmark west of Sheep Mountain has been recrystallized to a dolomitic marble, and is locally calcareous with minor silt and clay lenses. The dolomitic marble increases in coarseness and purity higher in the section. The estimated thickness at this locality is about 455 meters.

To the south near Moose Creek the Hasmark, by contrast, is neither metamorphosed nor sheared. It is generally fine to medium grained, crystalline dolomite. Although the color is typically white or beige, it is locally dark gray or black. Sandy-silty zones stand in relief on weathered surfaces. Silt sized quartz grains are disseminated within the dolomite which is generally thickly bedded with local thinly bedded horizons. Algal mats are relatively abundant in the top beds of this fault bounded block (Figure 9).

Table 3. The Wolsey-Hasmark transition zone west of Sheep Mountain. Included within the Hasmark map unit. Generalized lithology from float. No relative thicknesses to be inferred. Total thickness is about 60 meters.

Hasmark dolomite

Upper	<p>Very finely crystalline dolomite. Medium to dark gray with a slight orange cast on fresh surfaces, rusty limonite brown on weathered surfaces. Irregular knobby weathering texture with partially lithified carbonate chips broken out and redeposited and cemented. Chips are both tabular and spherical in shape.</p> <p>Very finely crystalline, very slightly calcareous dolomite. Rusty colored on weathered surface, decreasing inwards to a slightly iron stained buff color on fresh surfaces. Contains oxidized pyrite, including some cubes. Pyrite weathered out in places leaving small cavities. Iron stained halos around pyrite crystals and the weathered cavities. Largest pyrite crystal is 1.5 mm.</p> <p>Very fine grained, crystalline, dolomite. Gray on fresh surface, light brown on weathered surface. Relatively high fissility causes dolomite to weather out into shale like chips, probably silty. Paper thin dolomite veins parallel to plane of fissility. Localized, dark orange, earthy limonite zones.</p> <p>Aphanitic, dark purple, slightly calcareous dolomite. Silt-clay lenses 1 mm and less in thickness. Fine to medium grained sandy zones, without carbonate, and often hematitic. Weathered surface is dark gray.</p>
Lower	

Wolsey meta-shale and meta-siltstone

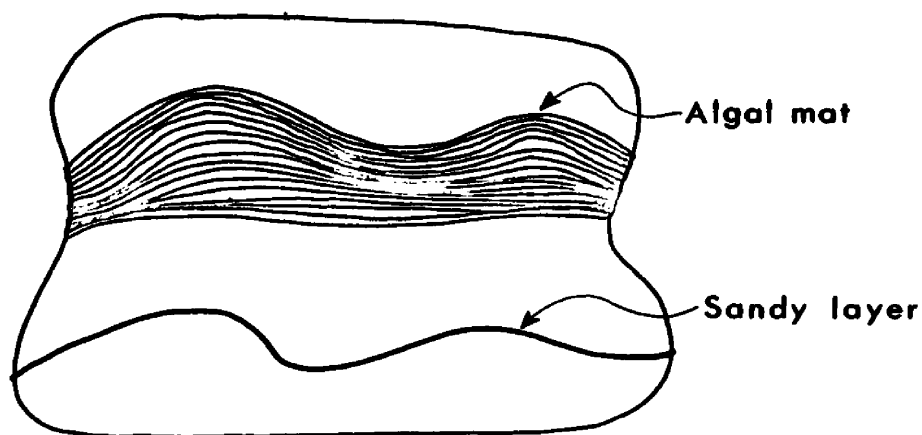


Fig. 9. Structures in the Hasmark dolomite near Moose Creek. 1 inch in figure equals about 4 feet.

Correlation and age. In central Montana, Middle and Upper Cambrian strata are assigned to the Flathead, Wolsey, Meagher, Park, Pilgrim, and Red Lion Formations. The western correlative of the Meagher-Park-Pilgrim sequence is the Hasmark Formation, originally described near Princeton, Montana by Emmons and Calkins (1913). The Meagher and Pilgrim Formations are limestones, but grade westward into dolomite, while the Park shale thins out and becomes silty dolomite. This predominantly dolomitic section is exemplified by the Hasmark Formation at Princeton. Because the sequence overlying the Wolsey west of Sheep Mountain is primarily dolomite, it is correlated with the Hasmark. However, its locally calcareous and silty nature suggest that it may be transitional between the central Montana limestone-shale-limestone facies and the western dolomite facies.

Useful fossils are rare in the Hasmark, probably because of the dolomitization process. Based upon stratigraphic position and correlation with the more fossiliferous central Montana formations, the Hasmark is assigned to the Middle and Upper Cambrian.

Table 4. The Hasmark Formation west of Sheep Mountain. Generalized lithology from float with no relative thicknesses to be inferred. Total thickness is about 455 meters.

Top not exposed

Upper Medium grained, very slightly calcareous, dolomitic marble. Grayish white on fresh surfaces, light brown to buff with shades of gray on weathered surfaces.

Very finely crystalline dolomitic marble (little or no CaCO_3). Buff gray on fresh surfaces, buff to tan on weathered surfaces. Bladed dolomite crystals within small cavities. Crystals up to 2 mm across. Minor small iron spots.

Extremely fine grained, massive, medium gray, Dolomitic marble. Buff tan on weathered surfaces. Paper thin silty-clay layers.

Silty layers typically 12-25 mm in thickness. Dolomite layers are also silty and moderately limonitic. Thin crossbeds(?) in dolomite layers. Silty layers are medium to dark gray or purple and the thicker limonitic dolomite layers are rust colored.

Lower Finely crystalline dolomite. Gray to rusty brown on weathered surfaces. Rust color gradually decreases into the rock. Fresh surfaces are very light pinkish brown. Minor paper thin clay-silt lenses.

Wolsey-Hasmark transition zone

Precambrian-Wolsey contact and the Wolsey-Hasmark contact

There is some disagreement concerning the Wolsey Formation with respect to the location of the Precambrian-Wolsey and Wolsey-Hasmark contacts. For the purposes of this study, the Wolsey was defined as the meta-shale and meta-siltstone unit which underlies the Hasmark dolomite and overlies the Precambrian meta-conglomerate. For reasons of field convenience, the Wolsey-Hasmark contact was mapped as the boundary between the relatively dark colored meta-shales and meta-siltstones, and the orange colored, shaly dolomites of the transition zone (Figure 10).

With a different interpretation, Obert (1962) and Mero (1962) essentially shifted the formation boundaries up one notch. The transition zone becomes the Wolsey and the meta-shales and meta-siltstones rather than the meta-conglomerates are the uppermost Precambrian unit (Figure 10). In the Black Lion Mountain area, Mero (1962) found that the meta-shale and siltstone unit was discontinuous and concluded that its upper surface represented a disconformity, and therefore was Precambrian. If the low areas on the Precambrian erosion surface received terrigenous sediments while the islands were later covered by carbonate sediments, the discontinuous shale and silt need not indicate a disconformity.

The lithologies described in Table 2 closely match Hansen's (1952) description of the typical Wolsey and the transition zone (Table 3) is similar to the limey shales, sand lenses, and intraformational limestone conglomerate that Hansen (1952) also described in the Wolsey. The thicknesses of both the shale-silt unit and the transition zone may have been exaggerated, and together they would correlate nicely with the other

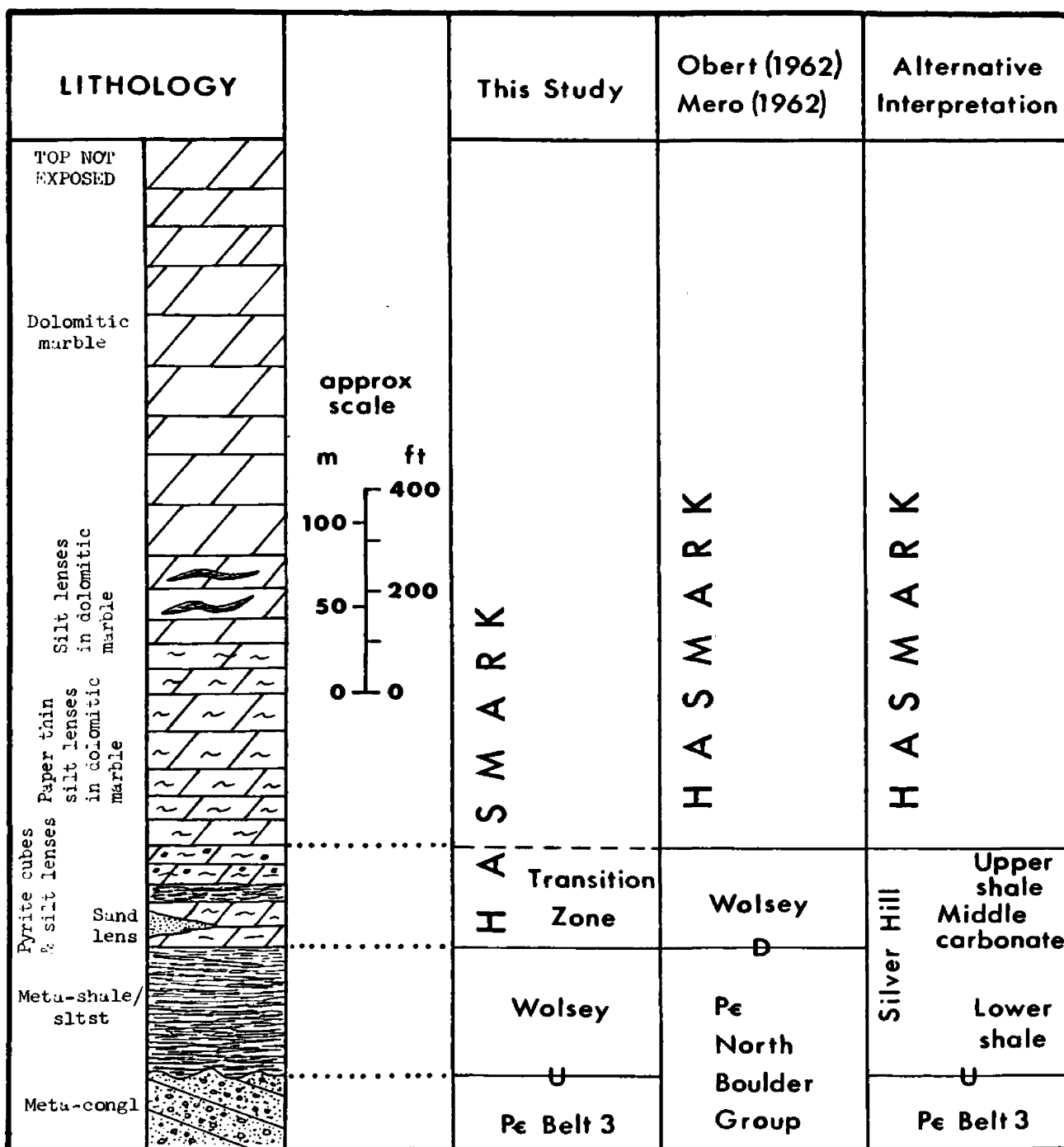


Fig. 10. Generalized Precambrian and Cambrian lithologic section west of Sheep Mountain. The formation boundaries used in this study are compared to the divisions made by Obert (1962) and Mero (1962). Column 4 illustrates an alternative interpretation. D=disconformity, U=angular unconformity

sections of the Wolsey. If an upper shale unit is found in the transition zone, the sequence would fit with the Silver Hill lower shale - middle carbonate - upper shale pattern.

CHAPTER IV

TERTIARY GEOLOGY

Introduction

Tertiary valley fill deposits, covering an area of approximately 13 square kilometers, unconformably overlie Precambrian Belt strata. The best exposures occur in a large slump scarp north of Fourth of July Ridge, and to the south along Gold Creek. In general, the sequence consists of fine grained stream and lake deposits, and mudflow fanglomerates. The fine grained deposits form the basal part of the section throughout the area whereas the fanglomerates are discontinuous and vary in lithology. Figure 11 diagrammatically shows the Fourth of July Ridge section.

These basin sediments are characterized by their lack of outcrop, and rolling and slumped topography. Meadow or sage brush covered slopes are more common than forested areas. The entire section is extremely incompetent and both large and small slumps may readily form.

Lithology

The fine grained deposits are generally thickly bedded, with no visible internal sedimentary structures. They form a 30 to 45 meter thick unit low in the section, and also occur interbedded with the fanglomerates near the top. These fine grained muddy rocks are about 90% clay which is mostly heterogeneously expandable mixed layer illite-smectite with less illite and kaolinite as determined by X-ray diffraction. Silt and

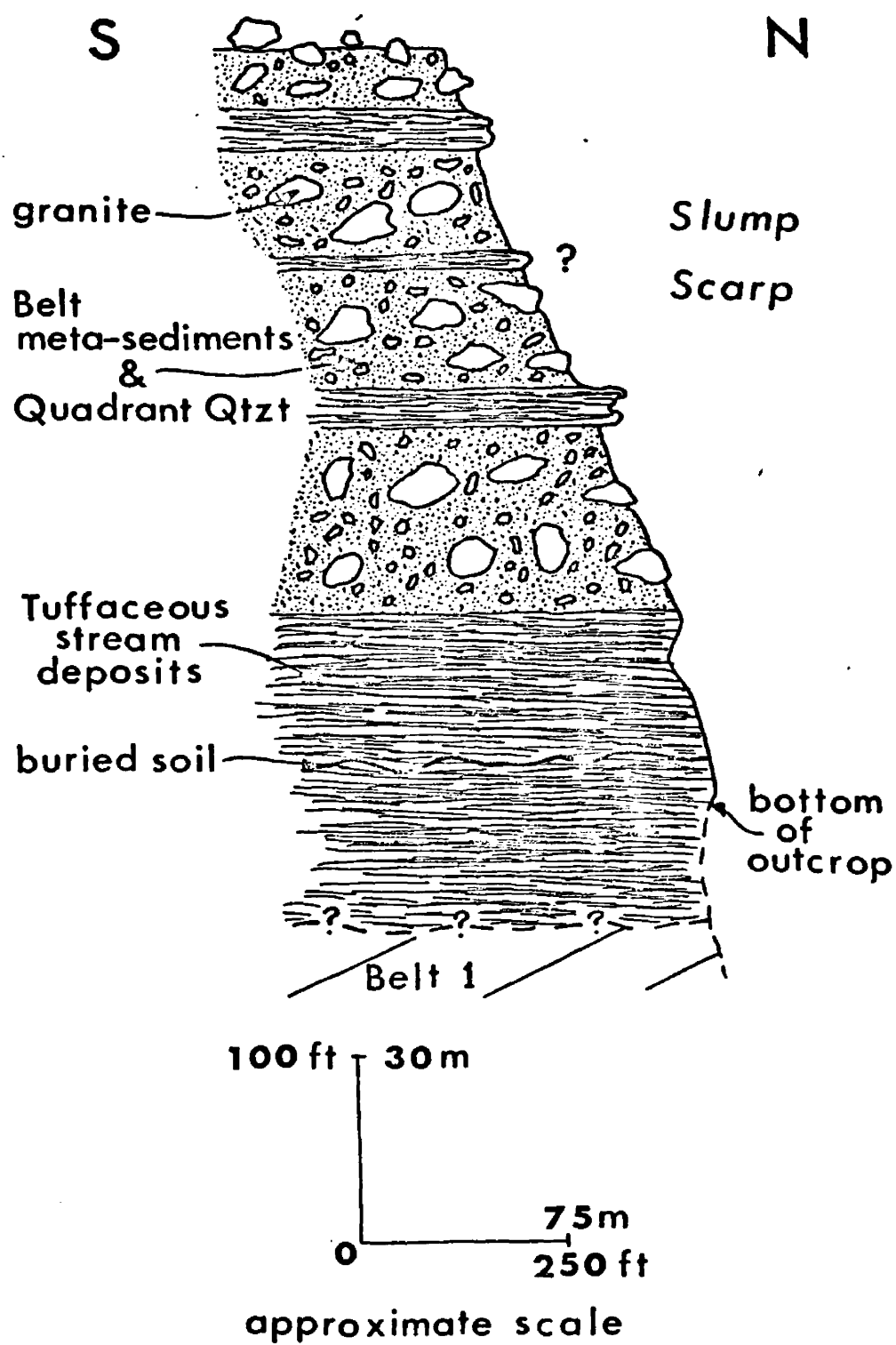


Fig. 11. Generalized Tertiary section north of Fourth of July Ridge.

very fine sand sized glass shards comprise most of the remaining 5-20% of the rock. Fresh feldspar grains (predominately plagioclase) account for 4-8% of the silt fraction, and there are trace amounts of biotite, chlorite, magnetite, hematite, and quartz. Although some mineral grains locally occur as euhedral crystals most are abraded to some degree. Sorting within the coarse fraction varies from moderately poor to poor. The lowest silty clay bed includes an indistinct buried soil profile.

By far the greatest percentage of the Tertiary section is composed of thick bouldery mudflow deposits. Near Fourth of July Ridge, the largest boulders are granitic and range up to 3.0 to 4.5 meters in diameter. Smaller cobbles and pebbles are granite, Precambrian quartzite, Precambrian feldspathic quartzite, and Quadrant quartzite. The mudflow matrix is arkosic sand and silt with some clay, probably similar to the clays of the fine grained beds.

Immediately north of Gold Creek, the fine grained strata are also overlain by a thick mudflow sequence. However, these conglomerates contain quartzite, not granite boulders, a marked contrast from the Fourth of July Ridge section. Because these boulders are derived from the closely jointed Belt and Quadrant quartzite sections, the maximum boulder diameter is about 0.6 meters with an average size of 0.3 meters. The matrix appears to be about the same at all localities.

Sediment source and genesis

The most likely source for these sediments is the high crest of the Pioneer Mountains to the east. The Tertiary is faulted against the granitic pluton, Belt strata, and Cambrian dolomite. With increasing

relief across the fault, the Tertiary basin filled with eroded Precambrian-Paleozoic formations and Cretaceous-Tertiary granites. The predominance of coarse fanglomerate high in the section indicates increased stream competence which is probably due to increased sheetwash over an un-vegetated landscape combined with higher relief and steeper stream gradients. The fanglomerates do not extend north of Sheep Creek. The grain size gradually decreases northward from the Fourth of July Creek area becoming only clay near Sheep Creek. If the absence of the fanglomerate is not due to post-Tertiary erosion, then these clays may represent the lake deposits of a closed basin mudflow, stream, and lake sequence. This would indicate a Tertiary Wise River Valley paralleling the modern valley, but slightly east of its present location.

Because the fanglomerates vary along the trend of this Tertiary valley, the source areas probably lay immediately to the east and west of the faulted Tertiary paleo-valley. Mudflow debris was apparently not transported beyond the mouths of the side valleys. Large granitic boulders occur in the Fourth of July Ridge section at the foot of the Clifford Creek pluton, but these granite boulders are absent near Gold Creek adjacent to Precambrian quartzites. These thick fanglomerates were thus deposited in the form of coalescing alluvial fans constructed across the main paleo-valley with lithologies directly related to their respective drainage basins.

As in virtually all Tertiary sections in southwestern Montana, glass shards are profuse and volcanic centers are scarce. Basaltic and andesitic lavas occur elsewhere within the surrounding region, but no sources have been determined. These silt sized glass shards are possibly quite far from their volcanic source.

Correlation

Age determinations within the Tertiary are generally based upon vertebrate fossils or structural relationships with radiometrically dated volcanics. Within the larger basins, the lithology generally reflects regional climatic and tectonic conditions, and some correlations can often be made on a lithologic basis. However, within small high mountain valleys such as the Tertiary Wise River Valley, local conditions may not coincide so closely with the regional climatic and tectonic setting. Pure lithologic correlations between the Wise River Tertiary sediments and the Tertiary deposits of larger basins in southwestern Montana are tenuous at best (S. Monroe, verbal commun., 1974).

Future research

Additional studies of the Tertiary deposits in the central Wise River Valley offer many possibilities. Tertiary sediments are distributed as far south as Elkhorn Creek and perhaps into the Grasshopper Valley. Nowhere within the study area are Tertiary deposits found west of the Wise River in the northern part of the range, except along the Big Hole River, and to my knowledge this limitation continues southward. The explanation for this distribution is undoubtedly connected with the structural history of the Pioneer Mountains.

Although no vertebrate fossils have been reported from the Tertiary in this area, no one has really searched for them. Such fossils would be of obvious importance in dating both the sediments and the faulting.

Detailed stratigraphic and lithologic descriptions, and correlations with source formations may reveal information concerning the paleo-topography

and drainage development within the central Pioneer Mountains. All of these Tertiary sediments cropout within 1-2 kilometers of the Wise River-Polaris road, and are therefore readily accessible to study. Useful outcrop, however, is scarce, occurring only where fresh slump scarps are located.

CHAPTER V

PLEISTOCENE GLACIAL DEPOSITS

Introduction

During the Pleistocene Epoch, extensive glaciers filled many valleys in the Pioneer Mountains. The Wise River and Pattengail glacial deposits were briefly examined by W. C. Alden (Alden, 1953).

Some valleys contained rock glaciers, ice glaciers, or both. Generally, the larger drainages supported glaciers composed predominantly of ice, whereas the smaller drainages were not capable of supplying the large quantities of ice necessary to form true glaciers. The smaller valleys, harboring rock glaciers, are now characterized by widespread "morainal" deposits throughout their valley bottoms, mostly with ill defined end moraines. These rock glaciers probably graded into periglacial scree slopes, which explains the vague boundary between scree and rock glacier deposits. By contrast, the larger valleys, which contained ice glaciers are relatively free of glacial till even though the evidence indicates that they contained large glaciers. These larger glaciated valleys will be discussed individually. Figure 12 is a location map for the features described throughout the rest of this chapter.

Boulder Creek

At its maximum, the Boulder Creek glacier, including tributaries, was 13 kilometers long (Figure 12). As evidenced by the abundant morainal debris within the main valley, this glacier, although probably not a rock glacier, was very dirty.

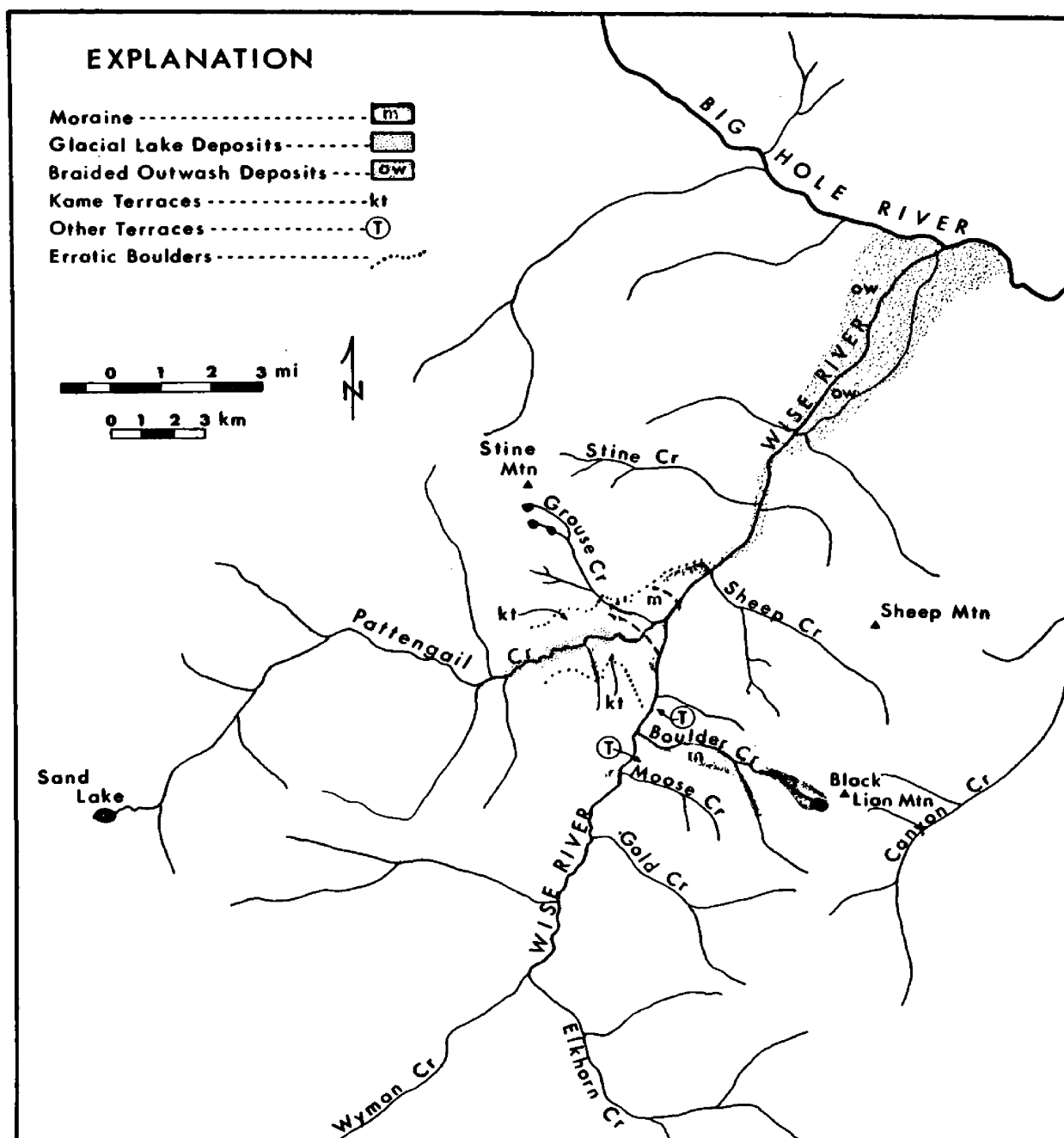


Fig. 12. Sketch map showing the locations of glacial features referred to in the text.

A large lateral moraine is the most prominent topographic feature along the south side of the Boulder Creek valley. This lateral moraine merges imperceptibly with the Boulder Creek terminal moraine which protrudes into the Wise River Valley. The south side of the glacier carried significantly larger quantities of debris, probably because the south fork tributary greatly extended the distance of ice-valley wall contact, making it 3.2 kilometers longer than the north wall. In addition, the south fork cuts easily eroded Precambrian meta-sandstones while the shorter north wall is primarily composed of massive granite.

The main valley contains what seems to be a classical sequence of recessional moraines consisting of the lower moraine which projects into the Wise River Valley, a smaller moraine near the junction of the north and south forks, and a very small moraine in the cirque. These are obviously progressively younger upvalley, but any attempt at regional correlation will require more detailed data.

Pattengail Creek

The Pattengail glacier extended nearly 24 kilometers from the southwest near Sand Lake to its terminus near the confluence of Sheep Creek and the Wise River (Figure 12). At its maximum, the glacier was about 275 meters thick within 1.5 kilometers of the Wise River as indicated by the upper limit of erratic boulders.

End moraines. There may be as many as three end moraines in the lower 2 kilometers of the Pattengail valley. These moraines form a complex pattern due to the number of advances and comingling with the outwash of the Boulder Creek and Wise River glaciers. Although possible divisions of this moraine are marked on Figure 12, they were inferred from air

photographs, and not distinguished on the ground. For this reason, the moraine is described as a single unit.

The proximal end, bordering the small glacial lake basin is definitely the most poorly sorted part of the moraine, containing boulders as large as 7.5-9.0 meters in diameter. The distal end is finer grained, better sorted, and stratified. The range of grain sizes is well within the transport capability of streams with moderate gradients. This material is, in fact, presently transported by the Wise River during spring floods. Tricart (1970) described how glaciers dump unsorted-unstratified debris on the upvalley parts of end moraines, and how sheetwash off the glacier terminus and emerging outwash streams deposit moderately well sorted and stratified sediments on the downvalley face. Although the Pattengail moraine extends across the Wise River Valley, there is little evidence to suggest that the moraine effectively blocked outwash flow down the valley from upstream glaciers for any long period of time. Much of the stratification, sorting, and rounding of these morainal sediments is probably due to contemporaneous reworking by the Boulder Creek and Wise River outwash streams as they flowed through the developing moraine.

The Pattengail glacier oozed up the Wise River as shown by the southward extending lobe of till, and the line of erratics which extends around the south wall of the Pattengail valley to finally meet the valley bottom about 1.5 kilometers up the Wise River. This line of erratic boulders probably marks the upper limit of the glacier-valley wall interface. If this deduction is valid, then the ice of the Pattengail glacier extended farther up the Wise River than is indicated by the moraines. The moraine

associated with the maximum advance, marked by the line of erratics, may have been washed away by an interglacial Wise River. Alternatively, the Wise River outwash streams eroded and redeposited the glacial debris slightly downstream as the moraine was forming.

Lateral moraines. Lateral moraines are sporadic along Pattengail Creek, and are preserved in a form that was originally quite perplexing. The small hanging valleys adjacent to the main valley all contain features that superficially appear to be well developed terminal moraines; landforms typical of heavily glaciated regions, but many of these valleys have not been glaciated. Furthermore, the rock debris contains lithologies foreign to the small, individual drainage basins. Evidently these "terminal moraines" are merely fingers of a lateral moraine left by protrusions of the Pattengail glacier which impounded the small valleys, leaving them hanging above the trunk stream. The lateral moraine is otherwise virtually absent. Perhaps these small valleys, acting as rather stagnant reservoirs of ice, tended to collect most of the sediment being carried along the ice margin, just as backwaters in rivers are filled by sediments.

Sediment load. The Pattengail glacier, in general, probably carried very little sediment. Air photographs indicate that the entire 24 kilometer length of the valley seems to be rather till deficient with Pattengail Creek flowing on granitic bedrock throughout most of its length. The granite is much more massive than the highly fractured Belt meta-sediments, so relatively little granitic debris was supplied to the glacier by mechanical weathering. In some cases, considerable quantities of till may be removed by a rapidly melting glacier. The absence of major recessional moraines

suggests that the Pattengail glacier did recede steadily with only a few short periods of stillstand. However, had great amounts of debris been fluvially eroded, they should have been deposited in the numerous low gradient reaches along the stream course.

Kame terraces. There are four distinguishable terrace levels exposed on the north valley wall in the lower 4 kilometers of Pattengail Creek (Figures 12, 13 and 14). The highest of these also occurs on the south valley wall. The higher degree of terrace development along the north wall may reflect a northward slope of the glacier surface due to the fact that the north side gets more direct sunlight. A northward slope may have directed both meltwater and sediment to the north edge of the glacier. The terraces are not continuous, perhaps because the ice marginal streams meandered on and off the ice. Terraces occur at approximately 187 meters, 190 meters, 194 meters, and 270-275 meters above the valley floor. These elevations will be more accurately known when the U.S. Geological Survey completes its topographic survey.

The upper kame terrace (270-275 meters) coincides with the upper limit of erratic boulders which in turn correlates with the maximum advance of the glacier (Figure 12 and Plate 1). This same episode is also primarily responsible for the morainal blockage of adjacent valleys because the line of erratic boulders also curves up these side drainages.

The four recorded episodes of terrace formation do not necessarily mean that there were four major glacial advances. They do indicate at least four periods of stillstand at approximately the same point because the terrace gradients projected downstream converge at about the same place.



Fig. 13. Upper kame terrace on the south valley wall of Pattengail Creek.
Arrow shows location.

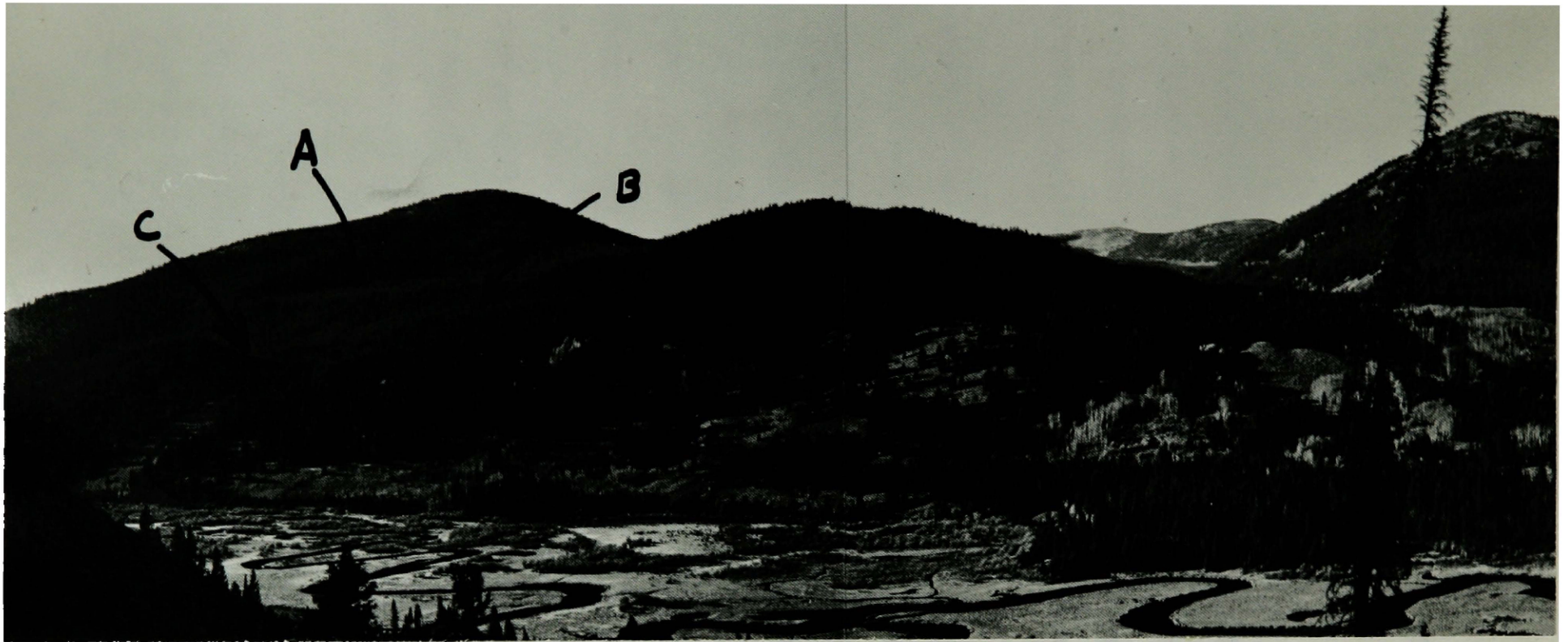


Fig. 14. Kame terraces on the north valley wall of Pattengail Creek. Arrows show locations. A=270-275 meters, B=194 meters, C=190 meters (elevations are approximate levels above the valley floor). The hanging valley in the right side of the photograph is Grouse Creek.

The highest and lowest terraces are better developed than the middle two. The preservation of the lower terraces indicates that each successively lower terrace is younger.

Wise River

The Wise River glacier was easily the largest glacier complex that existed in the Pioneer Mountains. Including tributaries, which drained an area of approximately 260 square kilometers, it may have been as much as 64 kilometers long, although within the Wise River valley proper it was only about 15 kilometers long. As shown in Plate 1, only the lower 1.5 to 2.5 kilometers of the glacier reached into the study area. Because the valley is quite wide (0.4-1.6 km) between Lacy Creek and Moose Creek, the glacier was probably only 60-90 meters thick (Alden, 1953).

Moraines. A very well formed end moraine near Moose Creek marks the maximum clearly definable advance of the Wise River glacier. Nicely arcuate in shape, the moraine is approximately 60 meters high and is quite steep on both sides. The east end overlies a bedrock knob of Precambrian meta-siltstone and meta-sandstone. As described by Alden (1953), a glacial lake formed behind this moraine and spilled over a low point on the east side, eroding away the till and through the bedrock. As a result, there is now a steep walled canyon where Moose Creek intersects the Wise River Valley.

Terraces. Two small terraces are present along the east side of the Wise River between Moose Creek and Boulder Creek, and between Boulder Creek and Fourth of July Creek. These terraces are all that remains of what was probably a thick outwash sequence formed by the Wise River and Boulder

Creek glaciers. The Wise River Valley is quite narrow between Moose Creek and Pattengail Creek and post-glacial fluvial erosion has virtually removed all glacial landforms in this part of the valley.

Outwash deposits

From Sheep Creek to the Big Hole River, the Wise River Valley displays beautiful terraces branded with a relict braided stream pattern. They were formed by well over 80 kilometers of melting ice, draining an area of nearly 600 square kilometers. Fraser and Waldrop (1972) noted at least four terrace levels within the Wise River Quadrangle, but only two stream terraces are apparent in the central Wise River Valley. The upper terrace was probably formed at the time of maximum glacial advance. Interglacial streams apparently eroded away most of this older deposit, leaving just one major remnant along the valley edge north of the Sheep Creek--Wise River junction.

The younger, lower terrace covers much of the valley bottom. Lithologically, near Butler Creek, the terrace is very poorly sorted with boulders as large as 45-60 centimeters suspended in a matrix of sand and silt. The average pebble size is about 5 centimeters and these pebbles and boulders are subrounded to rounded. As one approaches the large moraine complex at Pattengail Creek, the maximum boulder size increases dramatically up to 3 meters in diameter. Great quantities of silt, sand, pebbles and smaller boulders are also interstratified. In general, the maximum grain size decreases, and the stratification and imbrication increases as the distance downstream from the moraine increases.

The bottom curve in Figure 15 is a longitudinal plot of the lower terrace from Sheep Creek to the Big Hole River. The terrace profile shows

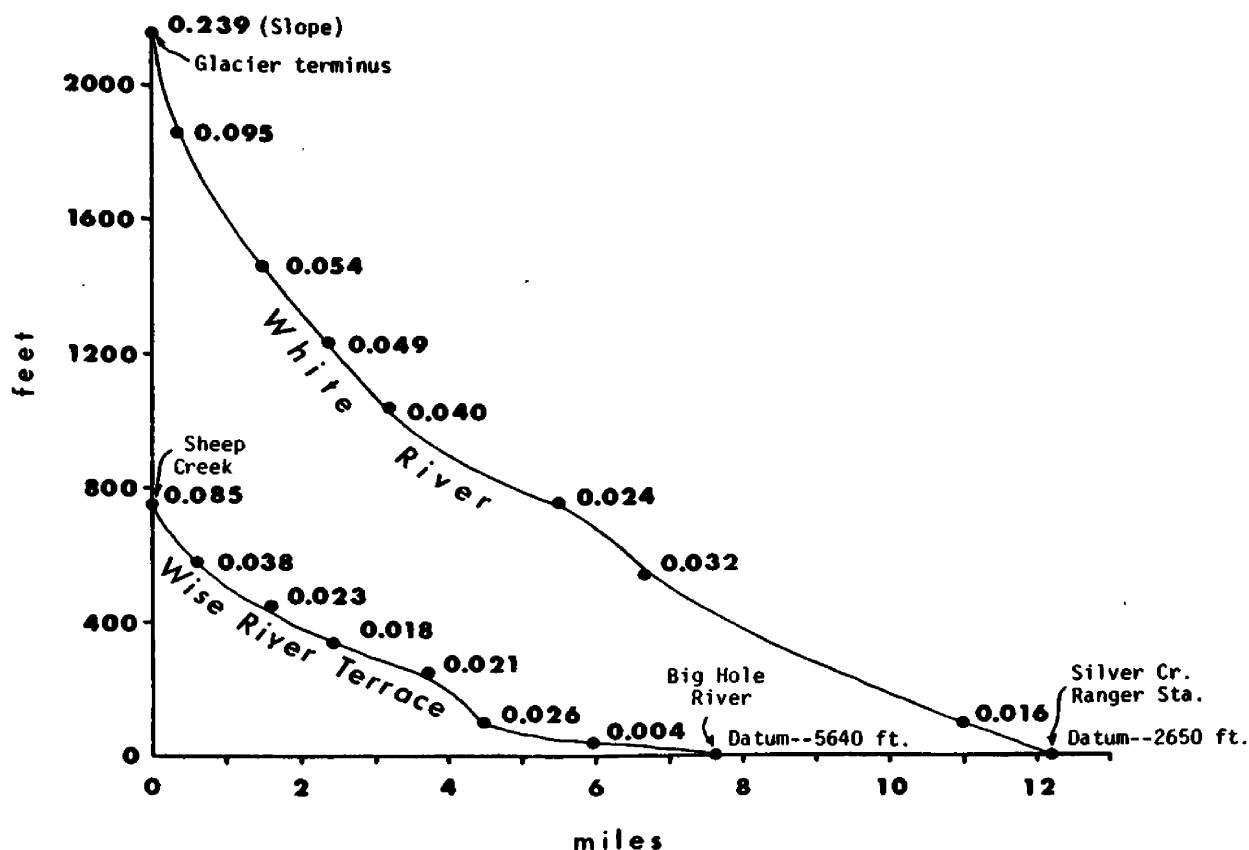


Fig. 15. Longitudinal profile of the White River, a modern glacial braided stream flowing off Mount Rainier, compared with the longitudinal profile of the lower braided stream terrace along the Wise River.

the typical concave upward shape, characteristic of normal river channels. Notice that the slope increases by 125% in the last kilometer (0.6 miles) before Sheep Creek. Just 0.2 to 0.3 kilometers farther up valley is the large Pattengail moraine complex. The White River (Figure 15, upper curve), a modern braided stream flowing off Mount Rainier studied by Fahnestock (1963), also shows a dramatic increase in gradient as it approaches its glacial source. This sharp increase in slope probably represents rapid deposition

downstream from the moraine as the river gradient steepens in response to the heavy sediment load.

The Wise River outwash sequence may lend itself to paleohydrologic studies based upon the work of Schumm (1972), and Leopold and Maddock (1953). Schumm (1972) found discharge to be directly related to the bank-full channel width and inversely related to the width to depth ratio. He computed the mean annual flood discharge by these relationships and then plotted it against the measured mean annual flood discharge. The correlation was very good. A similar comparison between calculated and measured mean annual discharge revealed a rougher correlation. Schumm (1972) attributed this to seasonal variations in flow, a complication that would be of critical importance in the case of fluvio-glacial braided rivers where seasonal discharges often differ radically. Because the terrace gradient should closely approximate the channel gradient, a comparison between gradient and sediment size may reveal more paleohydrologic data. The channel characteristics of this Wise River outwash deposit seem to be well enough preserved to make a study of the paleohydrology a feasible project.

Periglacial geology

The sections of the study area underlain by Precambrian meta-sandstone show some well developed periglacial landforms. These meta-sandstones are highly quartzitic, very brittle, and not easily weathered chemically.

Scree. The most obvious and well formed features are the abundant scree slopes. The slopes of the central Wise River Valley and Tricart's (1970) last stage of scree development are characterized by an extreme

scarcity of outcrop, especially along the sides of the valley bottom and on mountain tops. Outcrops occur mostly as scattered pinnacles or cliffs within the central third of the mountainside (Figures 16 and 17). In some places as much as 1.5 square kilometers may be free of soil or outcrop. The process of scree formation was probably a major contributor to the sediment load of the Pleistocene glaciers. Scree development is still very active as indicated by the lichen free debris, and the slopes are so unstable that even the weight of one person may cause significant down-slope movement.

Patterned ground. Where the scree evolution is quite advanced, and the mountain tops have been leveled off, patterned ground forms are moderately well developed. The most striking examples were found on the gently rounded mountain top immediately northeast of the lower half of Ross Gulch and on Stine Mountain.

The flatter parts of Stine Mountain are mantled with sorted stone circles. As described by Washburn (1956), this is a type of patterned ground which exhibits a circular rather than polygonal mesh design. The sorted types have centers of fine material bordered by coarser pebbles or boulders. The fine grained soily centers on Stine Mountain measure from 1.8 to 3.0 meters in diameter, are separated by distances of 4.5 to 9.0 meters, and stand as much as 0.3 meters above rings of very coarse debris which form a framework of inter-connected troughs.

The gently sloping scree on the mountain top northeast of Ross Gulch is deeply furrowed by long stone stripes. Soil is less well developed here than on Stine Mountain, possibly because the bedrock is more

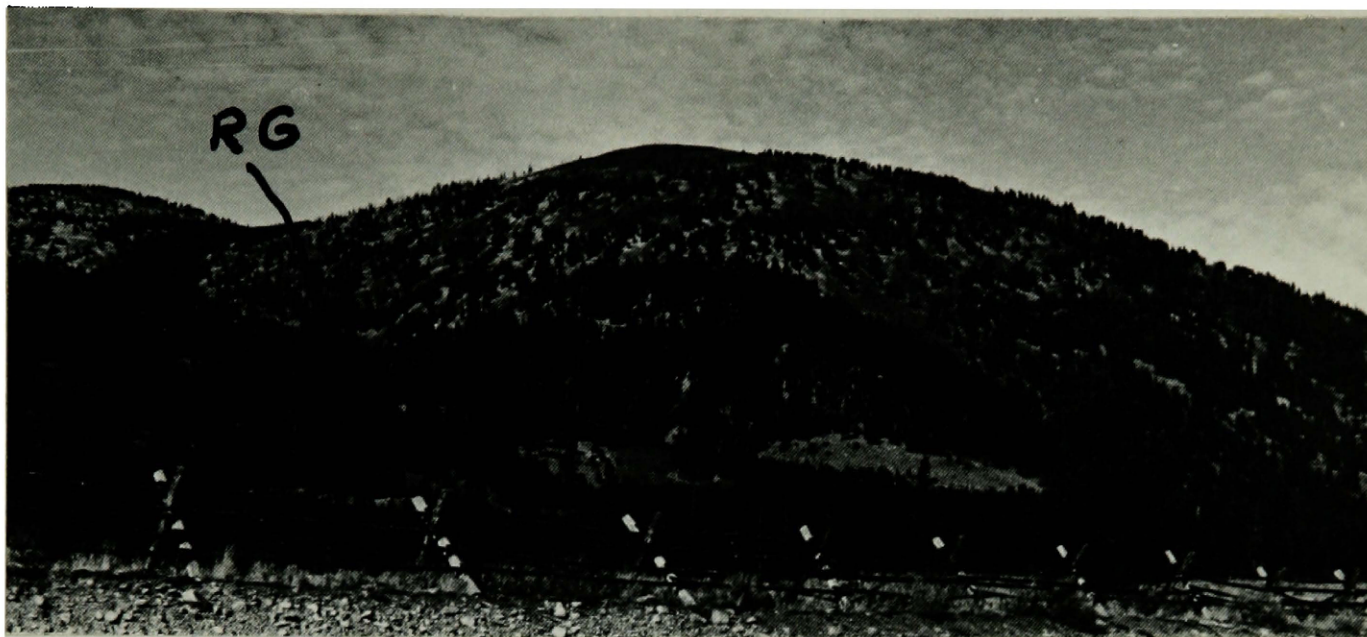


Fig. 16. Scree covered mountain north of Ross Gulch (see arrow).

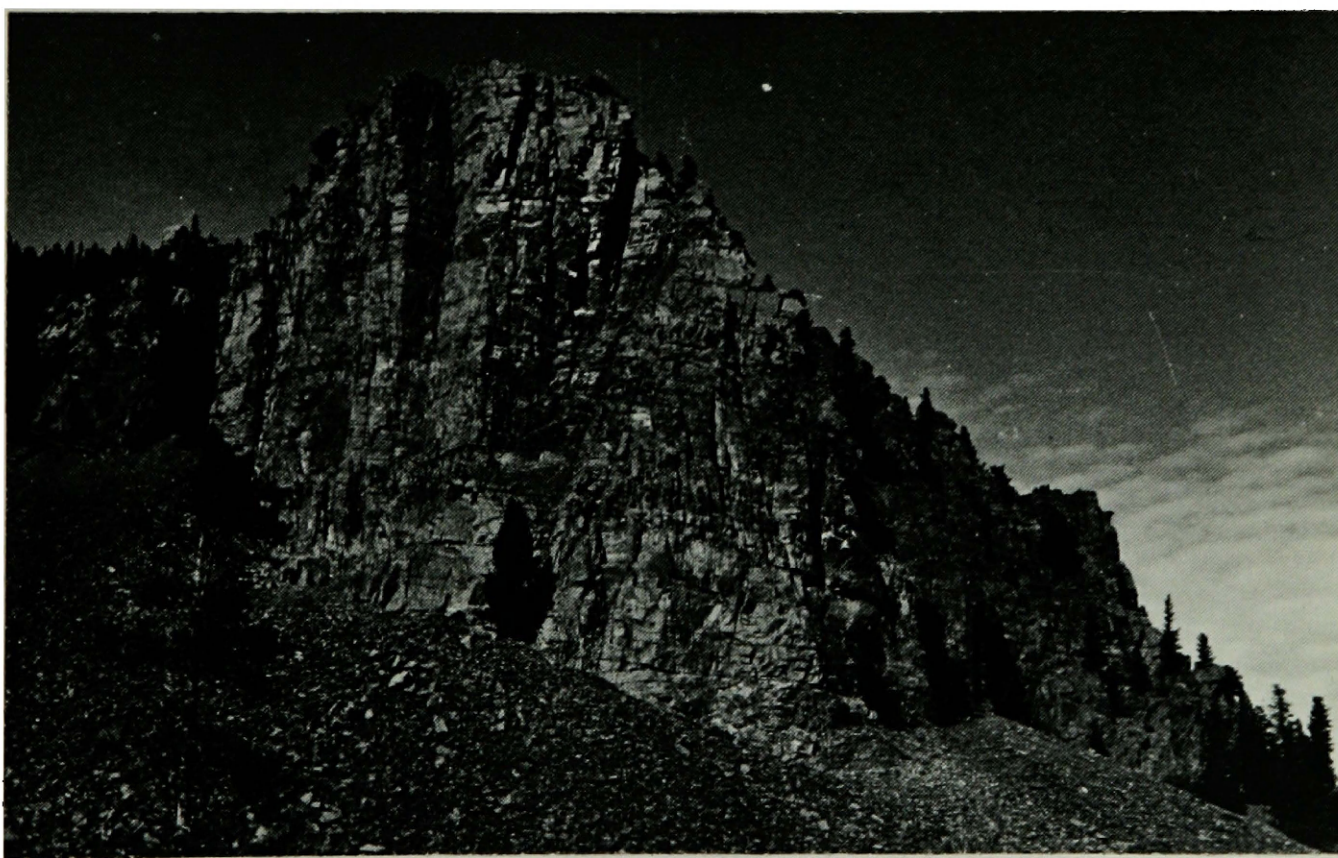


Fig. 17. Pinnacle cliff in scree along the Wise River.

uniformly medium grained sand without silty zones. The weathering boulders are also much larger and more equally sized, probably due to a more widely and regularly spaced joint system.

CHAPTER VI

IGNEOUS ROCKS

Introduction

Much of the northern and eastern parts of the central Wise River area are underlain by granitic rocks of the Stine Creek and Clifford Creek plutons. Composition ranges from diorite to granite, with granodiorite-quartz diorite being the most widespread. The Stine Creek pluton and the granitic rocks south of Boulder Creek are dominantly granite and granodiorite. Between Sheep Creek and Boulder Creek, the Clifford Creek pluton is composed of less silicic quartz diorites and granodiorites. Quartz and small pegmatite veins, and aplite dikes are present, but not very abundant. They are generally small with apparently no significant ore mineralization.

The granitic rocks, which readily weather to sand, do not crop out extensively, and areas underlain by granitic plutons are characterized by soil covered, rounded hills. Granitic pinnacles locally crop out on hill tops, and joint bounded cliffs are common along the walls of glaciated valleys, forming the freshest exposures.

Petrography

The more silicic rocks in the north and south parts of the central Wise River area are fine to medium grained and approximately equigranular. They contain about 50% quartz which is anhedral and commonly strained, locally with phenocrysts up to 5 millimeters in diameter. Plagioclase

of oligoclase-andesine composition composes 30-35% of these rocks. Plagioclase crystals are subhedral to euhedral, generally zoned, and typically altered to sericite and some sausserite. Albite twinning is ubiquitous and pericline and carlsbad twins are common. The total alkali feldspar content of these granites and granodiorites is typically about 15%, but the microcline/orthoclase ratio varies considerably. Orthoclase (0-15%) is anhedral, commonly altered to clay and locally micrographic. Microcline (trace-10%) is anhedral, but generally less altered to clay than orthoclase. In some cases microcline is poikilitic with quartz and in other instances patchy perthitic. Biotite (tr-5%) is euhedral-subhedral, pleochroic in shades of green and partly altered to chlorite. Accessory minerals are muscovite, epidote, magnetite, pyrite, zircon, and apatite. Zircon, epidote, and magnetite are most commonly adjacent to biotite grains. Anhedral epidote crystals do not appear to be altered from biotite although the two minerals are in most cases spatially associated. Some yellow, weakly pleochroic epidote crystals may have altered from plagioclase, and some are probably primary. Obert (1952) noted epidote in granitic rocks immediately northeast of the central Wise River area and attributed its presence to contamination of the magma.

The less silicic granitic rocks of the Clifford Creek pluton range from medium to fine grained, commonly with a moderate to wide variation in crystal sizes within a single sample. Quartz and plagioclase are generally subequal in size, averaging from 1-2 millimeters. Anhedral, strained quartz accounts for 35-50% of a typical sample and locally forms phenocrysts ranging up to 4 millimeters in diameter. Plagioclase

(30-60%) of oligoclase-andesine composition varies from euhedral to anhedral, is commonly zoned, and is altered to sericite and epidote. Orthoclase (tr-15%) is always anhedral, forming small interstitial grains. Microcline (0-5%) is anhedral and locally occurs as large perthitic or poikilitic crystals enclosing quartz, plagioclase, and biotite. The total alkali feldspar content ranges from 5 to 15%. Biotite (1-2%) is both euhedral and subhedral, is pleochroic in shades of green, and some has altered to chlorite and muscovite. Accessory minerals are muscovite, apatite, magnetite, ilmenite, sphene, zircon, and epidote. The last five are characteristically located around biotite grains. Some epidote is present as an alteration of plagioclase and some may be primary.

Mode of intrusion and structural relationships

Contacts between the various plutons and the country rocks are mostly covered. In those rare exposures that are relatively continuous, the contacts are sharp, although irregular in detail. Contacts are discordant, but in the north along the Wise River they locally approach concordance with the overlying Belt strata. Between Sheep Creek and Boulder Creek the contact between the Clifford Creek pluton and the Tertiary is marked by a fault. No clearly defined xenoliths were observed within the plutons, although they are common in plutons to the north and east (Obert, 1962; Mero, 1962; Moore, 1956; Theodosius, 1956; Fraser and Waldrop, 1972).

Near the mouths of Stine and Butler Creeks, the Stine Creek pluton underlies Belt meta-sediments, but farther west, the same pluton intrudes these Belt strata. The contact is irregular, but crudely follows the

contours along the Wise River, suggesting a near-concordant boundary with the nearly flat-lying Precambrian Belt strata. Fraser and Waldrop (1972) mapped much of the Belt rocks to the north as a large thrust plate, and found that the granites tended to spread out beneath the thrust plate, locally penetrating the upper plate. The outcrops along the Wise River are compatible with this interpretation.

Age relationships

Because there are no strata younger than Cambrian and older than Tertiary, the granitic rocks can not be accurately dated by field relationships within the central Wise River Valley. The Tertiary mudflows north of Fourth of July Creek contain boulders derived from the Clifford Creek pluton, and therefore the intrusion pre-dates these basin deposits. The fact that the granite also intruded the Middle Cambrian strata places the age between about 500 and 30 million years.

Moore (1956) and Theodosis (1956), in areas to the north and east, both found the granitic rocks intruding Upper Cretaceous sediments. Lower to Middle Tertiary lavas were extruded over an erosionally truncated granite-sedimentary contact in the Mount Fleecer area (Moore, 1956). The apparent age of the Pioneer plutons correlates closely with the Boulder and Philipsburg batholiths to the north. Based upon potassium-argon age data, Tilling and others (1968) showed that the Boulder batholith is probably between 68 and 78 million years old. A similar study by Hyndman and others (1972) indicates a 72-77 million year age for the Philipsburg batholith. No radiometric age dates are available for granitic plutons in the Pioneer Mountains. Although most of the field relationships

suggest an age of intrusion comparable to the batholiths to the north, there is evidence indicating that some of the Pioneer Mountains granites may be as young as Eocene (Meyers, 1952). Pattee (1960) also describes the granitic rocks of the Mount Torrey area (southern Pioneer Mountains) as Eocene.

Dikes

Several dikes are present within the central Wise River Valley. The largest (100 by 500 meters in outcrop), a metamorphosed fine grained mafic igneous rock, is located just west of the south fork of Boulder Creek. It cuts Precambrian meta-sandstones and is truncated by the Moose Creek fault. Plagioclase comprises 50% of the rock, is subhedral to euhedral, and highly sericitized. Hornblende (40%) is pleochroic in shades of green and blue green. The grains are very ragged in appearance with poorly developed cleavage, and are slightly altered to chlorite. Euhedral biotite (7-10%) occurs as circular clusters, in many cases with a blob of anhedral sphene in the center. Its pleochroic formula is X=very light tan, and Z=olive green. Anhedral quartz (1-3%) is very fine grained, and occurs interstitially giving the rock a patchy appearance in thin section. Magnetite (tr) is spatially associated with the sphene-biotite clusters. Texturally in thin section, the dike resembles one of "mother's experimental casseroles" with the biotite clusters and shredded hornblende lying on a bed of fine grained plagioclase and quartz.

A small, fine grained, porphyritic, garnet-biotite-plagioclase granodiorite dike cuts the Cambrian Hasmark Formation on the south flank of Sheep Mountain. Phenocrysts are dominantly euhedral plagioclase, but a few biotite and garnet phenocrysts are also present. Another

smaller dike, located slightly uphill, is extremely fine grained and appears to be a diorite.

Crystalline rocks of unknown origin

The rocks forming the ridge which trends northwestward from Sheep Mountain differ petrographically from other crystalline rocks in the area. There is some question as to whether these generally gneissic rocks belong to the border zone of a Laramide granitic pluton or whether they are pre-Belt metamorphic rocks. They appear to concordantly or nonconformably underlie Precambrian meta-sandstone and meta-conglomerate of the Belt 3 unit. To the west they are in fault contact with quartz meta-sandstones of the Belt 2 (?) unit. The gneissic structure becomes less pronounced to the northwest along the ridge. The gneissic layers vary in composition from quartz diorite in the light colored layers to diorite in the dark colored ones. A third rock type, a quartz diorite is not gneissic, but contains large hornblende megacrysts.

Petrography. The medium to fine grained quartz diorite layers are characterized by their light color, largely due to the high quartz content (40%). Plagioclase (30-40%) of oligoclase composition is anhedral in form. It is strongly altered to sericite and locally to epidote. Albite twinning, although very common, is not ubiquitous. Potassium feldspar (5-10%) is generally orthoclase, but includes rare microcline crystals. The K-feldspar grains are anhedral and highly altered, making the differentiation from untwinned plagioclase almost impossible. Biotite (1-20%) is euhedral to subhedral, pleochroic tan and greenish brown, and commonly altered to chlorite and rarely epidote. The freshest biotite

occurs as small clusters or crystals. Accessory and alteration minerals include muscovite, calcite, apatite, zircon, chlorite, and epidote.

The fine to medium grained dioritic layers are characterized by their darker color and occur as layers and pods within the lighter quartz diorite component. Plagioclase accounts for 60-70% of the rock. These largely anhedral grains are very heavily sericitized, and although twinning is very common, untwinned crystals are significantly numerous. There may be small quantities of potassium feldspar, but the high degree of alteration makes identification questionable. Biotite (20-30%), the second most abundant mineral, is present dominantly as an alteration of hornblende, but also as primary constituent. The primary biotite is altered to chlorite. Biotite grains range from euhedral to anhedral, and are pleochroic (X=light tan, Z=medium green). Hornblende (0-5%), anhedral to subhedral in habit, is at least partly altered to biotite. Wide variations in pleochroic colors from light beige to dark green are probably due to the alteration process. Accessory minerals are apatite, zircon, magnetite, and hematite.

The third rock type common to this ridge top is a nearly equigranular quartz diorite. Quartz grains (10-30%) are highly sutured, composite and semi-composite forms with moderate to strong undulose extinction. Plagioclase (30-70%), approximately oligoclase in composition, is generally anhedral to subhedral, and highly sericitized. Both twinned and untwinned grains are present. Almost all biotite (1-5%) is present as an alteration product of hornblende. Crystals are pleochroic in shades of brown and range in form from euhedral to anhedral, commonly showing a relict

amphibole cleavage. Hornblende (0-35%) is found in the groundmass and as megacrysts up to 15-20 milimeters in diameter which locally compose as much as 25% of the rock. The larger megacrysts are euhedral, but the smaller grains occur in anhedral or subhedral forms. All hornblende is pleochroic in shades of tan and green. The hornblende megacrysts are unevenly distributed, and most of the rock contains no fresh hornblende. However, in those sections lacking fresh hornblende, the biotite characteristically pseudomorphs the amphibole cleavage, indicating the original presence of hornblende. Accessory minerals are calcite, pyrite, apatite, sphene, and magnetite-hematite.

Geologic implications. From reconnaissance observations near Calvert Hill (Figure 2) in the northwest corner of the Pioneer Mountains, homogeneous equigranular granite appears to grade into gneissic rocks of granitic composition. The gneisses west of Sheep Mountain may be similarly related to a Laramide granitic pluton in the north-central part of the Pioneer Mountains as theoretically shown in Figure 18a. Because these gneissic rocks underlie probable Precambrian meta-sediments, the gneisses may be pre-Belt metamorphic rocks.

If these gneisses near Sheep Mountain are Precambrian, then the implications for a Late Precambrian orogenic event and movement along the Fourth of July fault are significant. At least 1500 to 1800 meters of Missoula Group strata represented by the Belt 1 and 2 units is missing east of the Fourth of July fault (Figure 18b). In order to juxtapose these two sections of rock, major horizontal and stratigraphic displacement across the Fourth of July fault is required. The upper and lower boundaries of the Belt 3 are unconformities marked Ux and Uy in Figure 18b.

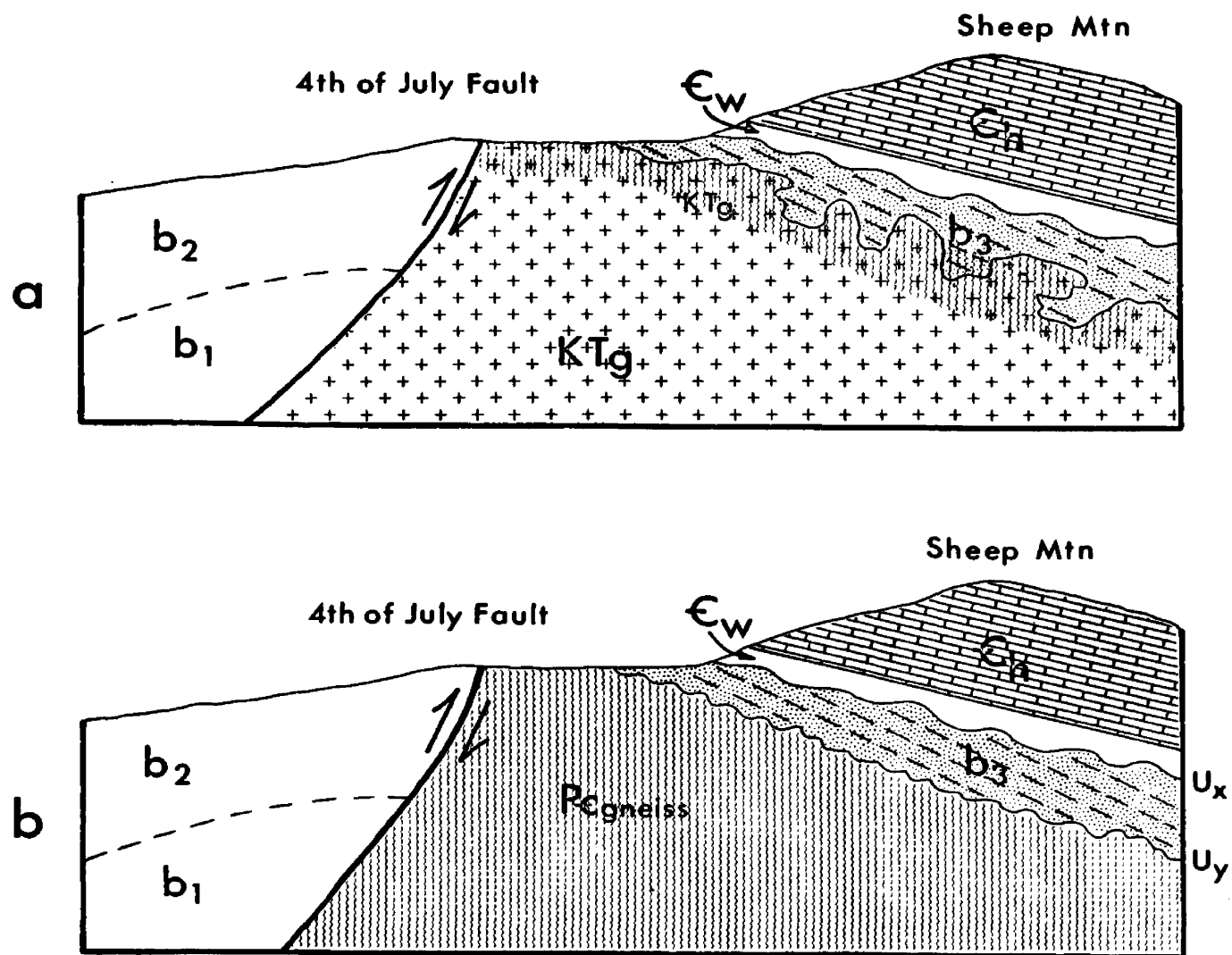


Fig. 18. Schematic cross-sections illustrating the implications of (18a) the gneiss west of Sheep Mountain as Laramide, and (18b) the gneiss as Precambrian. U_x and U_y are unconformities. See text for explanation.

Ux is the unconformity at the base of the Cambrian upon which the Wolsey shales and Hasmark carbonates were deposited. The nonconformity Uy suggests two possibilities. If the gneisses were part of the Dillon Block, they may have remained topographically high throughout most of the Precambrian; the Belt 3 representing the only Precambrian sedimentation on that erosion surface. The same nonconformity (Uy) could also indicate complete erosion of a once existing Belt sedimentary sequence (including Belt 1 and 2) followed by deposition of the Belt 3. Either of these two interpretations of the Uy nonconformity requires a great amount of displacement across the Fourth of July fault.

CHAPTER VII

METAMORPHISM

Regional metamorphism

Belt rocks. Precambrian Belt strata throughout the central Wise River Valley are metamorphosed to the biotite zone of the greenschist facies. Many post-depositional changes such as sericitization of feldspars, and overgrowths on quartz, feldspar, and tourmaline grains may be due to either diagenesis or low-grade metamorphism.

Unlike the moscovite grains which are bent around sand grains, no biotite appears to be detrital. Interstitial biotite, generally not much coarser than sericite, is common throughout most of the Precambrian Belt section, especially within the more pelitic layers. A few samples from the Belt 2 unit showed chlorite and biotite interpenetrating each other, but whether the reaction is prograde or retrograde is unclear. Several other samples, collected near the middle of the Belt 2 section from layers of almost pure quartz sand, contained chlorite, but no biotite. There may not have been enough potassium available in these feldspar free rocks to allow biotite generation. As a rule, in those rocks containing both biotite and chlorite, they appear to have formed separately in a largely sericitic matrix. Although chlorite was noted only within the Belt 2 unit, there were not enough thin sections of the uppermost Belt 3 unit to make a reliable survey. Sufficient thin sections of the Precambrian Belt 1 unit were examined to confidently establish the absence of chlorite.

Wolsey Formation. The alignment of sericite grains delineates a poorly developed foliation which is refracted across the thinly laminated bedding of the Wolsey shales and siltstones. Iron stained enechelon shear fractures parallel the foliation. The metamorphism is so slight that the poorly developed slaty cleavage and phyllitic sheen may be overlooked. No minerals are present which could be used to pinpoint the regional metamorphic grade, but it is probably not higher than lower greenschist facies.

Hasmark Formation. The dolomitic marble conformably overlying the Wolsey in the Sheep Mountain area is also sheared and recrystallized. No changes in mineralogy were observed, and these marbles are probably no higher grade than the Wolsey. Farther to the south near Moose Creek, the crystalline Hasmark dolomite is not sheared.

Contact metamorphism

Belt rocks. Where Precambrian Belt rocks are exposed within 30 meters of a granitic pluton, the effects of low grade contact metamorphism are usually superimposed upon the regional metamorphic characteristics. A particularly good exposure of this is located about 0.8 kilometers south of Stine Creek along the west side of the Wise River. The rocks are medium grained, crossbedded, feldspathic, quartz meta-sandstones regionally metamorphosed to the biotite zone, and contact metamorphosed to the albite-epidote-hornfels facies. Characteristics which are immediately obvious in the field include a sugary surface texture and spots. In thin section, the sugary texture is due to complete recrystallization of the quartz grains, largely obscuring the original grain boundaries and micro-

sedimentary textures. The feldspars (microcline and orthoclase at this locality) are much more thoroughly sericitized than is typical of those rocks subjected to regional metamorphism alone. Although the largest biotite and muscovite grains are adjacent to pegmatite veinlets, both minerals have also grown substantially throughout the contact zone. The spots, generally strung out along crossbeds marked by magnetite grains, are concentrations of relatively coarse grained biotite, muscovite, and quartz.

The albite-epidote-hornfels contact metamorphic facies roughly indicates temperatures similar to those of the greenschist regional metamorphic facies; the difference being the higher lithostatic and hydrostatic pressures, and shear stresses associated with regional metamorphism. The porphyroblastic growth of muscovite and biotite are attributed to the lower shear stresses of contact metamorphism.

Wolsey Formation. The Wolsey Formation west of Sheep Mountain has the contact metamorphic features of the albite-epidote-hornfels facies implanted upon the regional metamorphic fabric. These quartz-sericite, meta-shales, and meta-siltstones contain small spots (0.2--0.4 mm in diameter) composed of biotite, chlorite, and quartz. Chlorite, in many cases the only mineral forming a spot, also occurs in veinlets which cut the regional foliation at a low angle.

Hasmark Formation. Adjacent to small dikes of granodiorite and diorite, intense recrystallization imparts a fine grained sugary texture to the dolomitic marble. Samples collected from the contacts show no silica metasomatism of the marble.

CHAPTER VIII

STRUCTURE

Introduction

Unlike the tightly folded and faulted Paleozoic and Mesozoic strata along the eastern front of the Pioneer Mountains, the structures in the central Wise River area are broad. The differing tectonic styles may be related to the Johnson Thrust which appears to continue southward as the Fourth of July reverse fault, suggesting that the entire western part of the Pioneer Mountains has been moved eastward as a single sheet. The early-Laramide stress system was generally east-west compression whereas tensional basin and range style faulting has dominated from early-Tertiary to the present.

Fourth of July fault

The Fourth of July fault forms a major structural discontinuity through the eastern part of the study area, striking N40E at the north end and N-S at the south end. The zone of weakness expressed by the Fourth of July fault was characterized by reverse faulting during early-Laramide compression and by normal faulting during the Tertiary. The following discussion of the Fourth of July fault will begin with its origin as a reverse fault, followed by its Tertiary history as part of the basin and range fault system.

Regional significance--reverse faulting. The Johnson Thrust fault, mapped by Moore (1956), and Fraser and Waldrop (1972) in the Big Hole River

area, has moved Precambrian rocks (Belt 1 and 2 correlatives) westward over Paleozoic and Mesozoic rocks. As shown in Figure 19, the Fourth of July fault appears to be a southerly extension of the Johnson Thrust. Near Bonner Knob, Obert (1962) found Precambrian meta-sandstones faulted up against Cambrian Hasmark. The dashed lines connecting this fault with the Johnson Thrust cross an area covered by Pleistocene and Holocene deposits, and the dashed lines south of Bonner Knob follow the Precambrian-Cambrian contact which is locally offset by northwest trending normal faults. Note that as the Johnson Thrust curves back on itself at the southeast end, strike slip tear faulting marks the transition from a low to high angle fault plane.

The Pioneer Mountains can be divided into the following three tectonic terrains shown in Figures 19 and 20: (1) western terrain (Precambrian Belt 1 and 2), (2) mixed terrain (Precambrian Belt 3? and Paleozoic), and (3) eastern terrain (Paleozoic and Mesozoic). Figure 20, labeled X--Y in Figure 19, is a schematic cross section from the western terrain, through the mixed terrain, and into the eastern terrain. The Precambrian Belt rocks in the mixed terrain directly underlie the Cambrian and probably correlate with the Belt 3 unit mapped near Sheep Mountain, east of the Fourth of July fault. The western terrain, represented by Belt 1 and 2 rocks, is the allochthonous block whereas the mixed and eastern terrains are autochthonous.

Although the Fourth of July fault is very steep, it may flatten at a rather shallow depth, and a pod of highly sheared carbonate near the mouth of Ross Gulch may be a window of exposed Paleozoic rocks beneath Precambrian

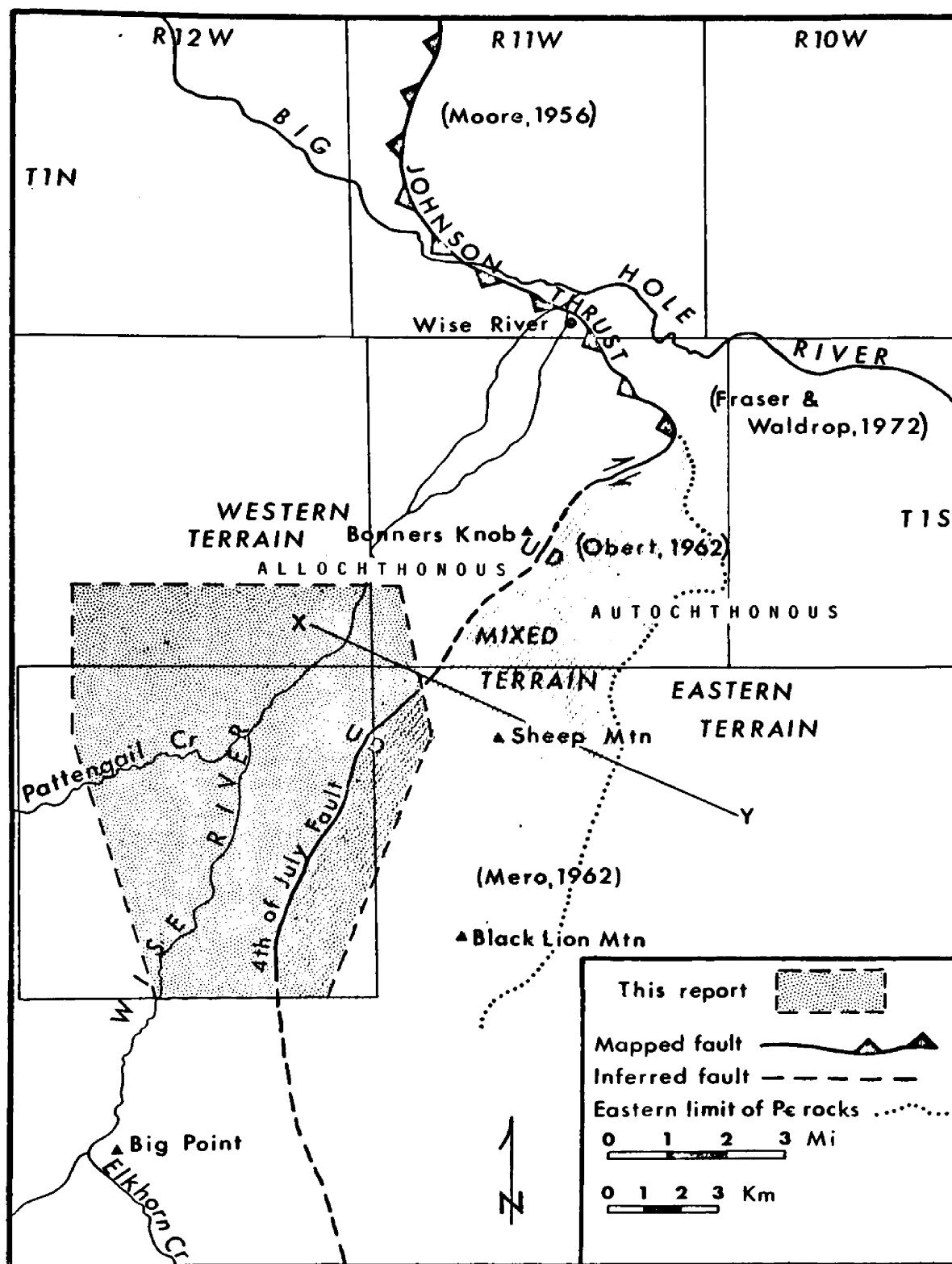


Fig. 19. Geologic sketch map showing the three tectonic terrains in relationship to the Johnson Thrust fault and the Fourth of July reverse fault.

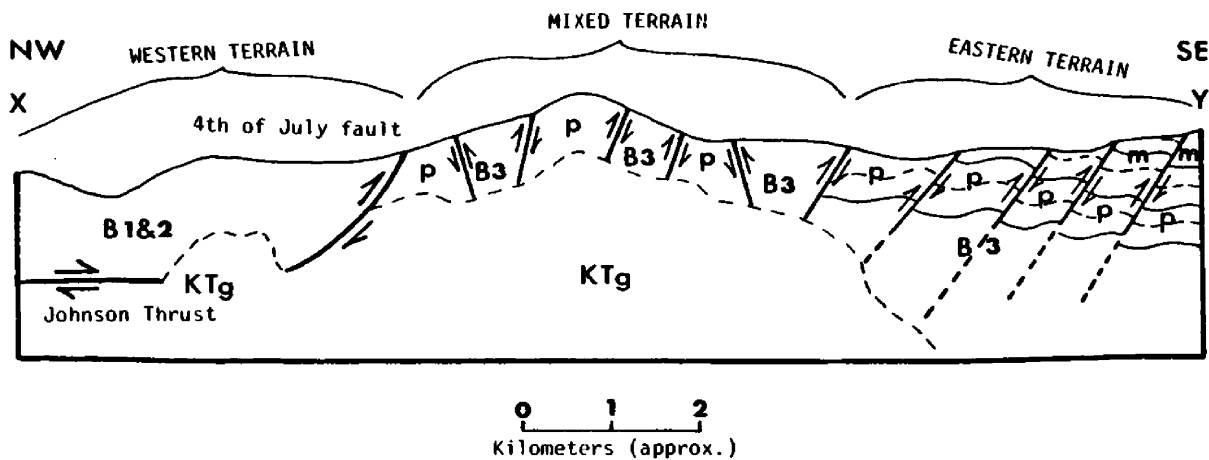


Fig. 20. Idealized cross-section across the three terrains outlined in Fig. 19. Beds and folds in the Paleozoic and Mesozoic are diagrammatic.
 B 1=Precambrian Belt 1, B 2=Precambrian Belt 2,
 B 3=Precambrian Belt 3, p=Paleozoic, m=Mesozoic,
 KTg=Cretaceous-Tertiary granitic rocks.

meta-sandstones (Plate 1). This carbonate is so completely sheared that definite formation identification is impossible. Moore (1956) described three separate occurrences of carbonate rocks along the sole of the Johnson Thrust which he interpreted as pre-Missoula Group Newland-Helena limestones. If other less sheared carbonate outcrops are found underlying Missoula Group strata, the thrust plate hypothesis may be better evaluated.

Age and type of fault movement. The oldest movement along the Fourth of July fault was reverse as shown in Figures 19 and 20, and Plate 2a. The major episode of crustal shortening occurred early in the Laramide orogeny (Moore, 1956; Fraser and Waldrop, 1972). Moore (1956) found a minimum horizontal displacement along the Johnson Thrust of 6.5 kilometers, and Fraser and Waldrop (1972) computed a horizontal displacement

of 11 kilometers with a stratigraphic throw of nearly 4 kilometers. The Laramide granites post date the major thrusting event, typically spreading out along the thrust plane and in some cases intruding the upper plate (Moore, 1956; Fraser and Waldrop, 1972).

Normal movement (up on the east side) predominated after the early Tertiary along the Fourth of July fault south of Sheep Creek (Plate 2b). The contact between the Tertiary and the Belt generally dips slightly eastward; while the fault contact between the Tertiary on the west, and the granite, Precambrian, and Cambrian on the east is nearly vertical. The normal component of movement appears to die out near Sheep Creek.

Fourth of July fault and Tertiary basin sedimentation. The Fourth of July fault marks the eastern edge of a Tertiary basin that formed a paleo-Wise River Valley. The inferred Tertiary movement along this fault is based primarily upon the characteristics of the Tertiary valley fill deposits immediately west of the fault. Because the Tertiary sediments are in abrupt contact with the granitic pluton from which the large granite boulders in the section were derived, the Fourth of July fault was apparently active during the formation of these valley deposits. Fine grained silt and clay deposits predominate in the lowest part of the Tertiary which suggests that stream competence was too low for the transportation of large boulders. As the Tertiary progressed, mudflows became more extensive, represented by the thick fanglomerate sequence typical of the upper Tertiary beds. The large Tertiary alluvial fans covered by sporadic mudflows may have been due to an arid climate, increased fault movement, or more likely, a combination of the two.

The dashed lines extending southward from the Fourth of July fault in Figure 19 are extrapolations based upon a linear alignment of valleys observed in high altitude air photographs. Large slumps were observed on the west, but not the east side of this theoretical fault trace, suggesting that the line continues to separate poorly consolidated Tertiary sediments from more massive bedrock.

Other faults

Major movement also occurred along several other faults. In the northeast corner of the study area a normal fault, which roughly parallels the Fourth of July fault, dropped white, quartz meta-sandstones of the Belt 2(?) down against the stratigraphically lower Belt 1 purple, feldspathic, quartz meta-sandstone (Plate 2a).

Moose Creek fault. The Moose Creek fault strikes in a N75W direction across the southern part of the central Wise River area. Extending the fault about 2 kilometers eastward along several photo-linears it connects with the Grace Lake fault mapped by Mero (1962). Because this fault cuts the Clifford Creek pluton and offsets the Precambrian-Tertiary contact it is probably no older than Middle-Tertiary (Plates 2c and 2d). Although the map (Plate 1) does not show it, the Moose Creek fault may be slightly offset by the Fourth of July fault which suggests still later movement along that major north-south fault. The stratigraphic throw across the Moose Creek fault is approximately 300 meters, based upon a 30 degree average slope on the Precambrian-Tertiary contact.

Grouse Creek and Ross Gulch faults. These two northwest trending, subparallel faults delineate a graben structure (Plate 2e). The center

downthrown block is assigned to the Belt 2 unit because it contains detrital plagioclase as discussed in the Precambrian chapter. A minimum offset of 760 meters across the graben is indicated by the Belt 1 conglomeratic horizon which occurs along the Wise River just north of Sheep Creek and south of Pattengail Creek.

Jointing

Two major joint sets cut the Stine Mountain area (Figure 21). They strike N38W and N67E, and dip approximately 80 degrees NE and SE respectively. These joints exerted significant control over the drainage development within the area. The lower 4.8 kilometers of Pattengail Creek parallels the northeasterly trending joint set; and Grouse Creek, Ross Gulch, and Sheep Creek align with the northwesterly trending system. The Ross Gulch fault also parallels the northwesterly joint set.

The main joint set within the Stine Creek pluton exposed along the Wise River is almost horizontal and probably results from unloading as the overlying Belt and Phanerozoic strata were removed.

Folding

Most of the Precambrian strata within the central Wise River Valley are part of a large monocline dipping to the southwest. This monocline flattens near Stine Mountain to the north and Moose Creek to the south. Interaxial distances must therefore be on the order of 9.5 to 16 kilometers for any large scale folds in the area.

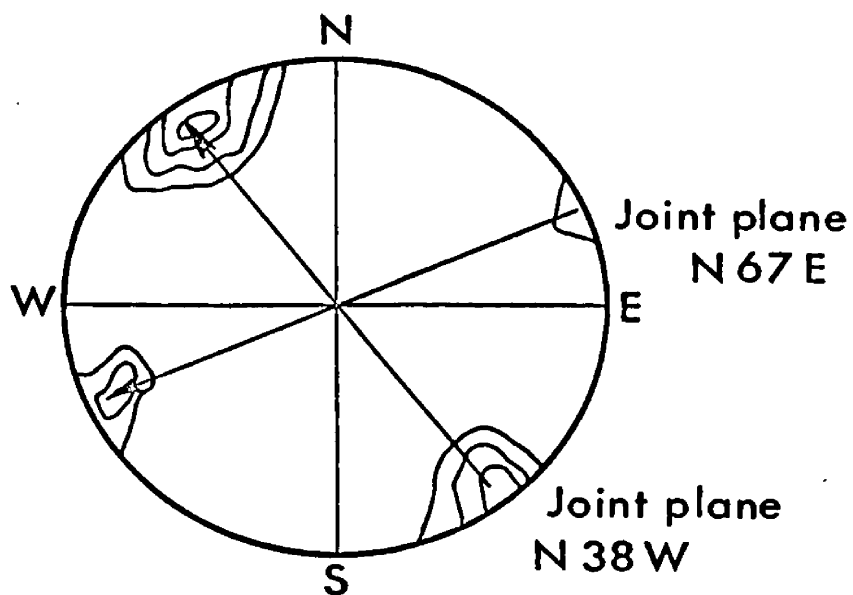
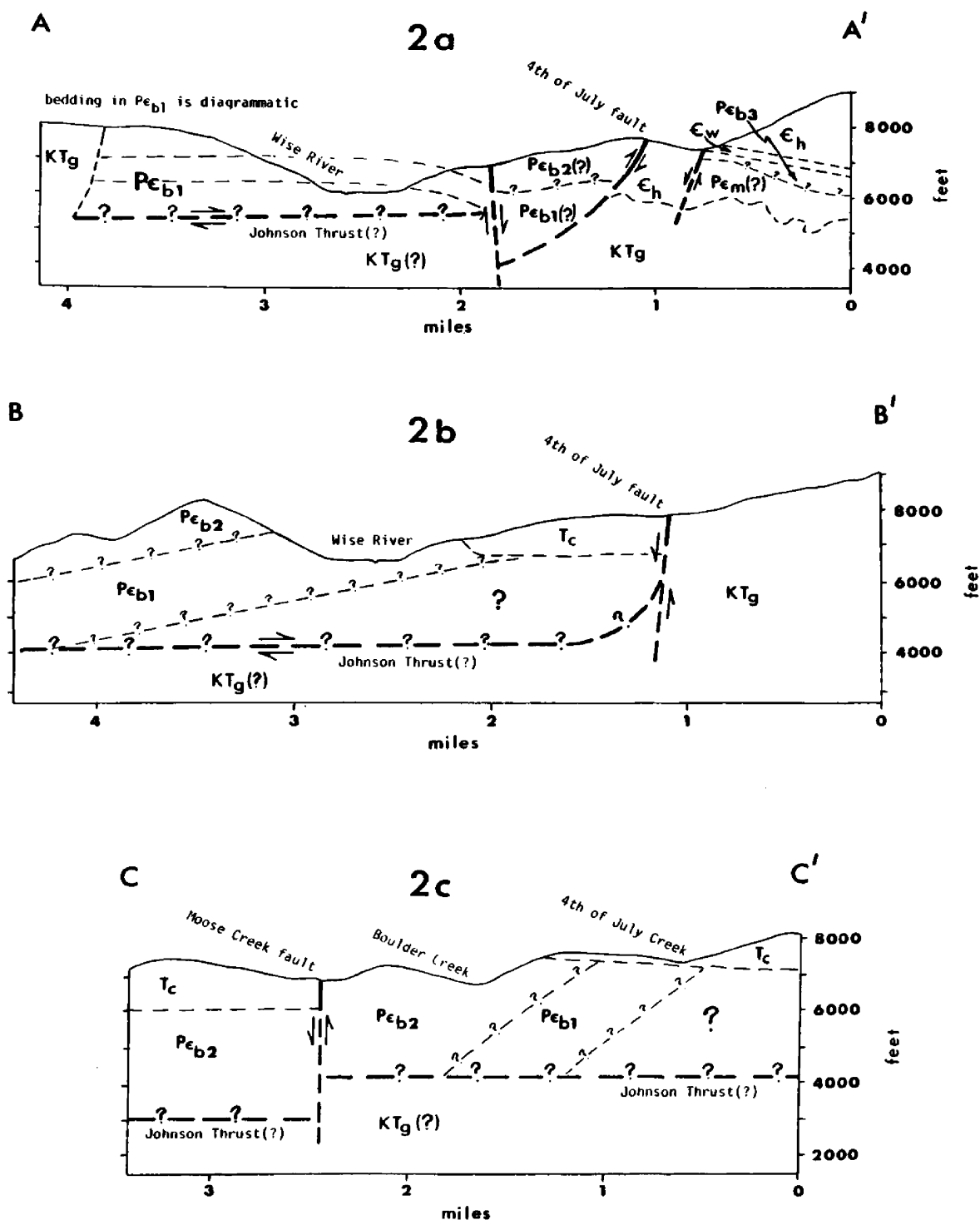
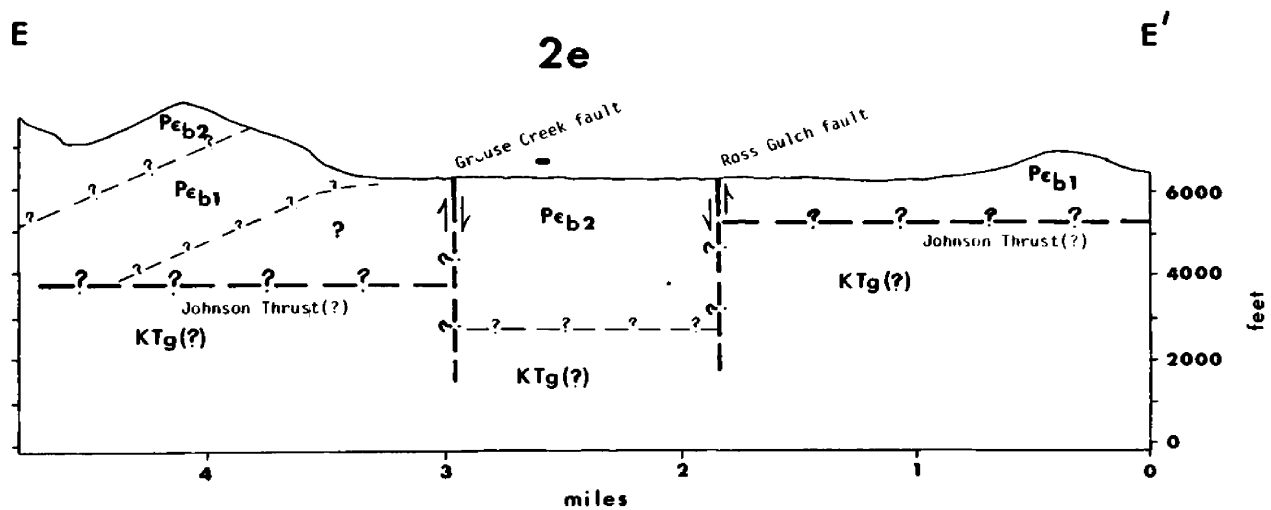
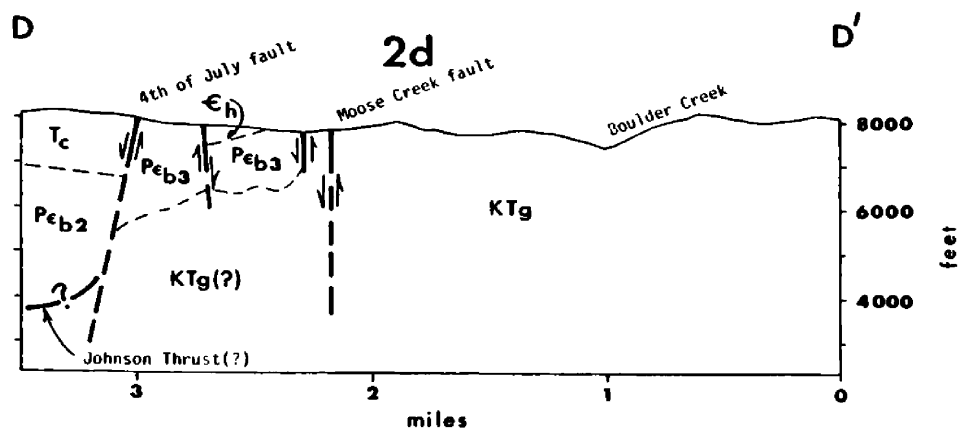


Fig. 21. Equal area stereo plot of joint orientations in the Stine Mountain area. 47 data entries. Contours are number of points/1% area--4/1, 6/1, 8/1, 10/1.

Plates 2a through 2e. Structure sections. See Plate 1 for locations.





CHAPTER IX

CONCLUSION--GEOLOGIC HISTORY

Introduction

Throughout western Montana, interpreting the paleogeography and regional sedimentary facies is made difficult because widespread thrusting has foreshortened east-west lines of section. The Missoula Group rocks of the central Wise River area appear to be part of an allochthonous plate which has moved eastward at least 11 kilometers (Fraser and Waldrop, 1972).

Geologic history

The barren alluvial plane, as interpreted by Winston (1973a, b, c) to represent Missoula Group sedimentation, certainly appears to be supported by the Wise River Precambrian sediments. In particular, the Belt 1 unit has been tentatively correlated as the coarse braided stream facies of the Bonner Formation (Winston, 1973a, b, c). The 1925-1830 meters of Precambrian conglomerate, sand, and silt were deposited by rapidly aggrading braided rivers which probably had their source in block faulted, lower Belt and crystalline rocks to the south and east. The Belt 1 and 2 units may be respectively interpreted as proximal and distal braided stream facies, but this does not necessarily imply any given distance from the source. Sometime during the uppermost Precambrian or Lower Cambrian, Missoula Group sediments were uplifted and eroded. If the Belt 3 unit does in fact unconformably overlies the older Belt 1 and 2

rocks, there is evidence of post-Belt 1 and 2 uplift, erosion, and deposition of the Belt 3 followed by uplift, erosion, and Cambrian deposition.

Deposition of Middle Cambrian Wolsey shales and Hasmark carbonates probably took place over an irregular Precambrian erosion surface of low relief. The local absence of Wolsey shales should not be interpreted as a disconformity, but rather suggests that carbonate was deposited directly on the higher Precambrian knobs that formed islands in the Cambrian sea while terrigenous deposits filled the low areas.

Rocks of Ordovician to Middle Devonian age are absent throughout the area (Moore, 1956; Noel, 1956; Theodosius, 1956; Fraser and Waldrop, 1972). Although within the study area the geologic record does not begin again until Late Cretaceous, all geologic periods from the Devonian through the Tertiary are represented in regions to the north and east.

Major thrust movement along the Fourth of July--Johnson Thrust fault system brought Belt meta-sediments up and over Paleozoic and uppermost Precambrian strata during the early stages of the Laramide Orogeny. After the period of major east-west compression, granitic intrusions spread out along the thrust plane, locally penetrating the upper plate (Moore, 1956; Fraser and Waldrop, 1972).

By Middle Eocene the Laramide granites were exposed, and by Late Eocene large block faulted interior drainage basins had formed in southwestern Montana (Hoffman, 1972). Block faulting, explosive volcanism, and basin filling were relatively continuous through the Pliocene (Hoffman, 1972; Kuenzi and Fields, 1971). At exactly what time the normal faulting and basin filling occurred within the central Wise River Valley is not clear.

Normal faulting along the Fourth of July fault was penecontemporaneous with Tertiary basin filling. The Tertiary sediments were later cut by the east-west trending Moose Creek fault and possibly the Grouse Creek and Ross Gulch faults as well. Still later activity along the Fourth of July fault may have displaced the Moose Creek fault.

Extensive ice and rock glaciers occupied most of the mountain valleys within the Pioneer Range during the Pleistocene, as evidenced by the widespread deposits of till in the valley bottoms. Glacial streams formed several large outwash terraces in the lower reaches of the Wise River Valley which still display a relict braided channel pattern. The scree covered mountainsides, which are still actively forming today, originally developed during glaciation.

Summary of major research problems

The three proposed Precambrian Belt units and the regional aspects of the "plagioclase line" need to be tested. The initial approach should include detailed stratigraphic descriptions of the strata within the central Wise River area and continued mapping in the western Pioneer Mountains.

An accurate determination of the stratigraphic position of the Belt 3 unit and the age of the underlying gneisses is probably the most pressing geologic problem within the northern Pioneer Mountains. Mapping of the granites and related gneisses near Calvert Hill and detailed mapping north and east of Sheep Mountain will provide information concerning the field relationships and possible origins of these problematical rocks. Various types of radiometric dating currently being used on the gneisses near Sheep Mountain may reveal important new data (Zen, verbal commun., 1974).

Continued study of the Fourth of July fault is critical to the tectonic history of the Pioneer Mountains and southwestern Montana. The inferred southerly extension of the Fourth of July fault and the correlation between this fault and the Johnson Thrust need to be field checked and refined.

The distinctively slumped topography characteristic of the Tertiary beds should make them easily identifiable in air photographs. Closer examination of these sediments for fossils and lateral facies changes may have important implications for paleo-topographic and drainage interpretations of the Pioneer Mountains.

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GEOLOGIC MAP OF THE CENTRAL WISE RIVER VALLEY AREA, PIONEER MOUNTAINS, BEAVERHEAD COUNTY, MONTANA

Geology by J.M. Calbeck

EXPLANATION

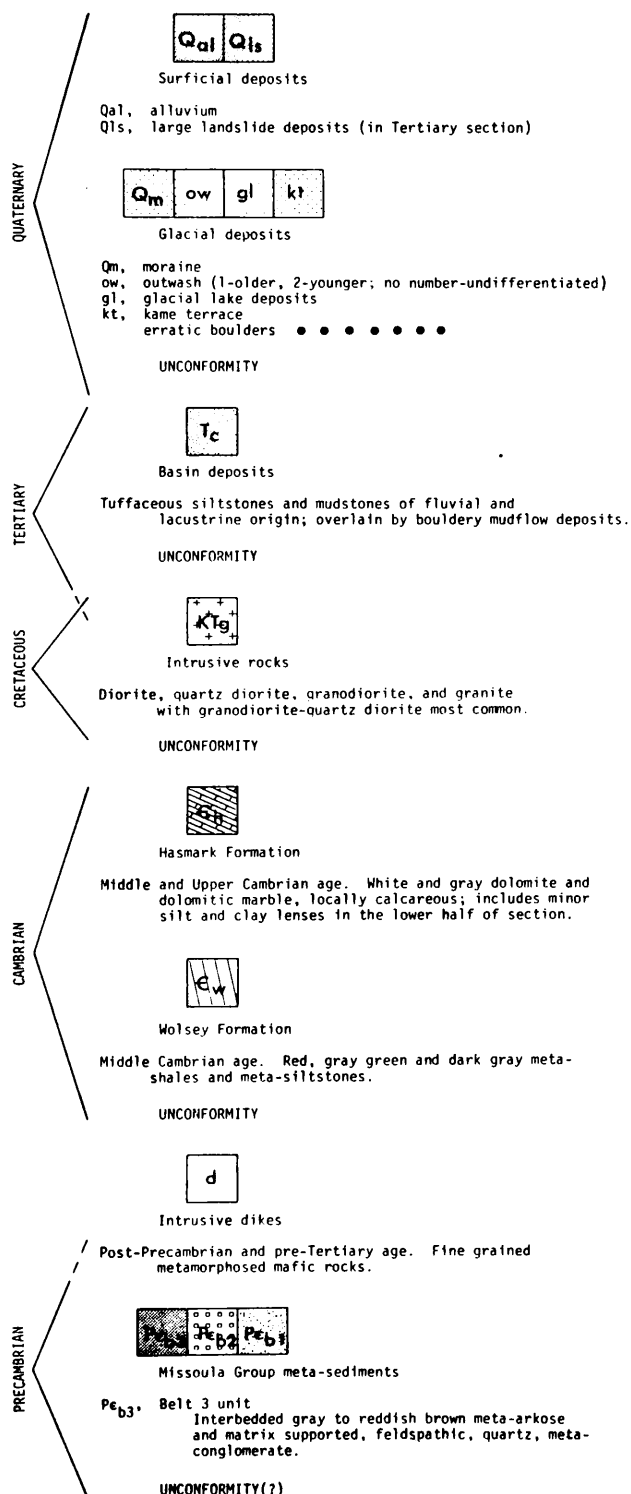


Plate 1

PRECAMBRIAN

Pe_{b2} Belt 2 unit
Gray and white to pinkish white, fine-medium grained, feldspathic quartz, meta-sandstone; and quartz meta-sandstone. Planar and ripple crossbeds, and plane beds. Purple and green meta-siltstone and very fine grained meta-sandstone with wave and current ripples, and mudcracks on bedding planes. Detrital plagioclase.

Pe_{b1} Belt 1 unit
Dark to light purple with some white colored meta-sandstone. Abundant festoon, planar, and ripple crossbeds. Some minor plane beds. Microcline, orthoclase, and quartz. Very coarse, matrix supported, meta-conglomerate with arkosic matrix. But dominantly medium to coarse grained, arkosic, meta-sandstone.

SC

Sheared carbonates of unknown age at mouth of Ross Gulch.

UNCONFORMITY

Pe_{m?}

Possible Pre-Belt quartz diorite gneiss.

-----?-----?

Contact

Dashed where approximately located, queried where inferred.

U
D
Fault

Long dashed where approximately located, short dashed where concealed, queried where inferred. U-upthrown side; D-downthrown side.

45°

Strike and dip of beds

8

Generalized strike and dip of bed

⊕

Horizontal or very nearly horizontal beds.

A A'
Line of cross section

True North

18°

Magnetic North

Approximate mean declination, 1972

Base map--U.S. Forest Service 1:31,680 planimetric map. 200 foot contours are from the Army Map Service, Dillon, Montana 1:250,000 topographic map. Present map copy is photo-reduced, see bar scales.

1 .5 0 1 Mile
1 .5 0 1 Kilometer

Contour interval 200 feet
Datum is mean sea level